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SOILS


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SOILS

THEIR

FORMATION, PROPERTIES, COMPOSITION, AND RELATIONS TO CLIMATE AND PLANT GROWTH

IN THE

HUMID AND ARID REGIONS

BY

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New York
THE MACMILLAN COMPANY
LONDON: MACMILLAN & CO., Ltd.
1914

Set up and electrotyped. Published July, 1906. Reprinted August, 1907 ; January, 1910 ; April, 1911; September, 1912; September, 1914.

Norwood Press:
Berwick & Smith Co., Norwood, Mass., U.S.A.

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PREFACE.

THIS volume was originally designed to serve as a text- and reference book for the students attending the writer's course on soils, given annually at the University of California, who complained of their inability to find in any connected treatise a large portion of the subject matter brought before them. As all these students had preliminary training in physics, chemistry and botany, no introductory chapters on these general subjects were necessary or contemplated; the more so as good elementary treatises embracing the needful preparation are now numerous.

As time progressed, however, outside demands for a book embodying the writer's soil studies in the humid and arid regions, especially the latter, became so numerous and pressing that the scope of the work has gradually been much enlarged to conform to these demands; and this, rather than completeness of detail, when such detail can be found well given elsewhere, has been the guide in the necessary condensation of the whole. To give the entire subject matter full elucidation, would require several more volumes.

It may not be unnecessary to explain at the outset why and how this treatise deviates in many respects from previous publications on the same general topic. From boyhood up it has fallen to the writer's lot to be almost continuously in more or less direct contact with the conditions and requirements of newly settled regions, as well as with those hardly yet invaded even by the pioneer farmer; where the question of cultural adaptation was yet undetermined or wholly in the dark. Being during his active life constantly called upon in his official capacity to give information and advice to pioneer farmers or intending settlers in regard to the merits and adaptations of virgin soils, the writer's attention was naturally and forcibly directed toward soil investigation as a possible means of determining, beforehand, the general prospects and special features of agriculture in regions where actual experience was either non-existent or very brief and partial. In the pursuit of these studies he has been favored by exceptional opportunities, extending over a varied climatic area reaching on the south from the Gulf of Mexico to the Ohio, across to the Pacific coast, and to British Columbia on the north. That a systematic investigation of soils over so large an area, covering both humid and arid regions, should lead to some unexpected and novel results, is but natural; and it is the discussion of these results in connection with those obtained elsewhere, and with some of the prevailing views based thereon, that must serve as the justification for the present addition to an already well-stocked branch of literature.

From the very beginning of the scientific study of agriculture, the investigation of soils with a view to the *à priori* determination of their adaptation, permanent value, and best means of cultural improvement, has formed the subject of continuous effort. It is not easy to imagine a subject of higher direct importance to the physical welfare of mankind, whose very existence depends on the yearly returns drawn by cultural labor from the soil.

It is certainly remarkable that after all this long-continued effort, even the fundamental principles, and still more the methods by which the object in view is to be attained, are still so far in dispute that a unification of opinion in this respect is not yet in view; and a return to pure empiricism is from time to time brought forward to cut the Gordian knot.

While this state of things is primarily due to the intrinsic complexity and difficulty of the subject itself, it has unquestionably been materially aggravated by accidental, partly historic conditions. Foremost among these is the fact that until within recent times, soil studies have borne almost entirely on lands long cultivated and in most cases fertilized: thus changing them from their natural condition to a more or less artificial one, which obscures the natural relations of each soil to vegetation.

The importance of these relations is obvious, both from the theoretical and from the practical standpoint. From the former, it is clear that the native vegetation represents, within the climatic limits of the regional flora, the result of a secular process of adaptation of plants to climates and soils, by natural selection and the survival of the fittest. The natural floras and sylvas are thus the expression of secular, or rather, millennial experience, which if rightly interpreted must convey to the cultivator of the soil the same information that otherwise he must acquire by long and costly personal experience.

The general correctness of this axiom is almost self-evident; it is explicitly recognized in the universal practice of settlers in new regions, of selecting lands in accordance with the character of the forest growth thereon; it is even legally recognized by the valuation of lands upon the same basis, for purposes of assessment, as is practiced in a number of States.

The accuracy with which experienced farmers judge of the quality of timbered lands by their forest growth, has justly excited the wonder and envy of agricultural investigators, whose researches, based upon incomplete theoretical assumptions, failed to convey to them any such practical insight. It was doubtless this state of the case that led a distinguished writer on agriculture to remark, nearly half a century ago, that he "would rather trust an old farmer for his judgment of land than the best chemist alive." [1]

It is certainly true that mere physico-chemical analyses, unassisted by other data, will frequently lead to a wholly erroneous estimate of a soil's agricultural value, when applied to cultivated lands. But the matter assumes a very different aspect when, with the natural vegetation and the corresponding cultural experience as guides, we seek for the factors upon which the observed natural selection of plants depends, by the physical and chemical examination of the respective soils. It is further obvious that, these factors being once known, we shall be justified in applying them to those cases in which the guiding mark of native vegetation is absent, as the result of causes that have not materially altered the natural condition of the soil.

It is probable that, had agricultural science been first developed in regions where the external conditions permitted the carrying-out of such a course of investigation, instead of in the abnormally temperate, even and humid climate of middle

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[1] "The Soil Analyses of the Geological Surveys of Kentucky and Arkansas." S. W. Johnson in *AM. JOUR. SCI.*, Sept. 1861.

Europe, with its long-cropped, worn fields, and very predominantly calcareous soils, the present condition of this science might differ not immaterially from that actually existing. As a matter of fact, it has attained its present state under very disadvantageous external conditions, which frequently necessitated a recourse to highly complex and laborious methods and artificial appliances, for the establishment and maintenance of the conditions which elsewhere might have been found abundantly realized in nature; thus permitting, by the multiplication of observations over extended and widely varied areas, the elimination and control of accidental errors of experiment and observation.

Just as in historical geology the subdivisions of formations observed and accepted in Europe formed for many years a procrustean bed upon which the facts observed elsewhere had to be stretched, so in the domain of soil physics and chemistry, and even in vegetable physiology, the observations made in the really exceptional climates and soils of middle Western Europe, have often erroneously been construed as constituting a general basis for unalterable deductions.

The rapid extension of civilization and the carrying of minute scientific research into other regions, now rendered possible by the improved means of communication, has shown the one-sidedness of some of the views prevailing heretofore, inasmuch as they are really applicable only to accidental and rather exceptional conditions.

It is therefore one object of this volume to present and discuss summarily the facts of physical and chemical soil constitution and functions with reference to the additional light afforded on the wider basis, embracing both the humid and the arid regions; of which the latter has, as such, received but scant and desultory attention thus far, to the detriment of both the work of the agricultural experiment stations and of agricultural practice. The book therefore includes the discussion both of the methods and results of direct physical, chemical and botanical soil investigation, as well as the subject matter relating to the origin, formation, classification and physical as well as chemical nature of soil, usually included in works on scientific agriculture.

In the presentation of these subjects, it has been the writer's aim to reach both the students in his own classes and in the agricultural colleges generally, as well as the fast increasing class of farmers of both regions who are willing and even anxious to avail themselves of the results and principles of scientific investigation, without "shying off" from the new or unfamiliar words necessary to embody new ideas. It would seem to be time that the latter class, and more especially those constituting farmers' clubs, should learn to understand and appreciate both the terms and methods of scientific reasoning, which are likely to form, increasingly, the subjects of instruction in the public schools. But in order to segregate to some extent the generally intelligible matter from that which requires more scientific preparation than can now be generally expected, it has been thought best to use in the text two kinds of type; the larger one embodying the matter presumed to be interesting and intelligible to the general reader, while the smaller type carries the illustrative detail and discussion which will be sought chiefly by the student.

As regards the chemical nomenclature used in this volume, the writer has not thought it advisable to follow the example set by some late authors in substituting for the well-known names of the bases and acids, those of the elements, and still less, those of the intangible ions. Any one who has taught classes in agricultural chemistry will have experienced the difficulty and loss of time unnecessarily incurred in the incessantly recurring transposition of terms, and complication of formulæ, serving no useful purpose save that of academic consistency. It is of at least doubtful utility to present to the farmer, *e. g.*, the inflammable and dangerous elements phosphorus and potassium as prime factors in the success of his crops, and of healthy nutrition.

Inasmuch as all the elements are presented to and contained in the plant in compounds only, and these compounds are themselves, in the dilute solutions used by plants, known to be largely dissociated into their basic and acid groups, it seems to be most natural to present them under the corresponding, even if not absolutely theoretically correct names of acids and bases, to which the farmer and the trade have been accustomed for half a century. Upon these considerations the long-used designations of potash, soda, lime, phosphoric, sulfuric, nitric and other acids and bases have been retained in this volume, adding the chemical formula where, as in analytical statements, a doubt as to their meaning might arise. Assuredly, the diffusion of scientific knowledge should not be needlessly hindered by the adoption of a pedantic mode of presentation.

The great breadth of the subject of this volume has rendered inadvisable any extended bibliography, such as it has of late become customary to add to works of this kind. References have therefore been restricted to publications specially discussed, and to such as are not widely known on account of limited circulation.

The author's warmest acknowledgments are due to Professor R. H. Loughridge, of the University of California, for efficient and sympathetic assistance, both in the revision of the manuscript, and active personal help in the preparation of the illustrations. Without his coöperation the preparation and publication of the volume would have been much longer delayed.

Acknowledgments are also due for helpful suggestions and criticism to Professors L. H. Bailey, of Cornell University, F. H. King, of Wisconsin, and Jacques Loeb of the University of California.

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BERKELEY, CALIFORNIA,
November 15, 1905.

INTRODUCTION.

Definition of Soils.—In the most general meaning of the term, a soil is the more or less loose and friable material in which, by means of their roots, plants may or do find a foothold and nourishment, as well as other conditions of growth. Soils form the uppermost layer of the earth's crust; but the term does not indicate any such definite average texture as is sometimes implied by its popular use to designate certain loose, loamy materials found in older geological formations. We do find in these, not unfrequently, layers that in the past have served to support vegetation, as evidenced by remains of plants found therein. But as a rule, such ancient soils are much compacted and otherwise changed, and would not now be capable of performing the office of plant nutrition without previous, long-continued exposure to the same agencies by which all soils were originally formed from pre-existing rocks. Within the latter category must be included, in scientific parlance, not only the hard rocks known as such in daily life, but also such soft materials as clay, sand, marls, etc., which often compose, partially or wholly, the bodies of wide-spread geological formations.

Elements Constituting the Earth's Crust.—More than seventy elementary substances have been found within the portion of the earth accessible to man; most of these are present only in very minute proportions; of those occurring in relatively considerable quantities, a list showing their approximate proportions is given below.

Average quantitative composition of the Earth's Crust.—The total thickness of the outer shell of the earth, thus far known to us, does not exceed about 95,000 feet, as observed in the accessible rock deposits. Estimates of the proportions in which the more abundant elements contribute to the composition of these constituent rocks, have repeatedly been made. The latest and most widely accepted of these, by F. W. Clarke, of the U. S. Geological Survey, is given herewith. It includes the constituents of the sea and atmosphere as well; these two constitute about 7 per cent of the whole, 93 per cent being solid rocks.

RELATIVE ABUNDANCE OF THE ELEMENTS TO A DEPTH OF TEN KILOMETERS.

	Solid Crust (93 Per Cent).	Ocean (7 Per Cent).	Mean, Including Air.
Oxygen	47.29	85.79	49.98
Silicon	27.21		25.30
Aluminum	7.81		7.26
Iron	5.46		5.08
Calcium	3.77	0.05	3.51
Magnesium	2.68	0.14	2.50
Sodium	2.36	1.14	2.28
Potassium	2.40	0.04	2.23
Hydrogen	0.21	10.67	0.94
Titanium	0.33		0.30
Carbon	0.22	0.002	0.21
Chlorin	0.01	2.07	0.15
Phosphorus	0.10		0.09
Manganese	0.08		0.07
Sulphur	0.03	0.09	0.04
Barium	0.03		0.03
Nitrogen			0.02
Fluorin	0.02		0.02
Chromium	0.01		0.01

It will be noted that one-half of the total consists of oxygen, and that nearly 86% (or 47.29% of the 49.98%) of this amount is contained in the solid rocks; nearly 2.50% of the remainder in sea and other water; and .41% in the atmosphere, in the free condition, in which it serves for the respiration of animals and plants, and for the various processes of slow and rapid combustion, or "oxidation." This relatively small proportion of the whole, is, nevertheless, the most directly important for the maintenance of organic life.

Oxids Constitute Earth's Crust.—The vast predominance of oxygen in the above list suggests at once that most of the other elements must exist in combination with it, *i. e.*, as "oxids." H. S. Washington[1] has lately revised the estimates heretofore made, on the basis of a very large number of analyses made by him and others, of rocks within the United States, and gives the following table; alongside of which is placed a revised estimate by Clarke, which also includes rocks from abroad; both being given in terms of oxids of the several elements.

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[1] U. S. Geol. Survey, Professional Paper No. 14, p. 108.

		WASHINGTON.	CLARKE.
Silica	SiO_2	57.78	59.89
Alumina	Al_2O_3	15.67	15.45
Peroxid of Iron	Fe_2O_3	3.31	2.64
Protoxid of Iron	FeO	3.84	3.53
Magnesia	MgO	3.81	4.37
Lime	CaO	5.18	4.91
Soda	Na_2O_1	3.88	3.56
Potash	K_2O	3.13	2.81
Water, basic	H_2O+	1.42	1.52
Water, acid	H_2O-	.36	.40
Ferric Sulphid	FeS_2	1.03	.60
Phosphoric acid	P_2O_5	.37	.22
Manganese Protoxid	MnO	.22	.10

The salient point which at once attracts attention in these tables is the great predominance of the oxid of silicon—silica, silicic acid, quartz, etc.,—over all other substances. While quartz occurs alone in enormous masses, as will be shown later, probably the greater proportion is found in combination with other oxids, notably those of aluminum, calcium, iron, magnesium, and the alkali metals potassium and sodium. Chlorin and fluorin, however, do not occur as oxids.[1]

The Chemical Elements Important to Agriculture.—Of the numerous elements known to chemists, only eighteen require mention in connection with either soil formation or plant growth; and of these only thirteen or fourteen participate in normal plant growth. They are the following:

METALLIC ELEMENTS.

Potassium
Sodium
Calcium
Magnesium
Iron
Manganese
Aluminum
Titanium

NON-METALLIC ELEMENTS.

Carbon
Hydrogen
Oxygen
Nitrogen
Phosphorus
Sulphur
Chlorin
Fluorin
Iodin
Silicon.

Of this list, titanium, though a very constant ingredient of

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[1] A trifling amount of chlorin is found oxidized in the form of sodium perchlorate, in the nitre deposits of Chile.

soils in the form of titanic dioxid, is not known as performing any important function in soils, and is not, so far as known at present, ever taken up by plants. Aluminum, in the form of its compounds with oxygen and silicon, is a very prominent and physically very important soil ingredient, but does not, apparently, perform any direct function in plant nutrition, and is absent from their ash, except in the case of some of the lower plants (horsetails and ferns).

Iodin appears to be normally present in all seaweeds, and occurs in traces in some land plants. Fluorin is a normal ingredient of animal bones, and its presence in plant ashes is often easily shown. The remaining fourteen, however, are always present in plants; carbon, hydrogen, oxygen and nitrogen forming the volatile or combustible part, while the rest occur in the ashes.

It is true that other elements, or rather their compounds, are sometimes found in plants, being taken up by them from solutions existing in the soil. Thus the alkalies caesium and rubidium, also barium, strontium, zinc, copper, boron and some others, may be absorbed when present in soluble form. But they are neither necessary nor beneficial to plant economy, and when in considerable amounts are harmful. Thus fifteen elements, ommiting iodin and titanium, alone require discussion.

The Volatile Part of Plants, as already stated, consists of carbon, hydrogen, oxygen and nitrogen. Of these, carbon is obtained by the plant exclusively from the carbonic (dioxid) gas of the air; hydrogen and oxygen, from the soil in the form of water; nitrogen, directly from the soil but indirectly also from the air, through the agency of certain bacteria. The *ash ingredients* of course are all derived from the soil through the roots, and must all be present in the latter in an available form, to a sufficient extent to supply the demands of vegetation.

The Agencies of Soil Formation.—With respect to their mode of formation, soils may be defined as the residual product of the physical disintegration and chemical decomposition of rocks; with, ordinarily, a small proportion of the remnants of organic life. The agencies producing these changes are those classed under the general term "atmospheric" or "meteorological;" they include therefore the action of *temperature*—heat and cold—that of *water,* and that of *air and its ingredients.* In popular parlance, it includes the processes of *weathering;* nearly the same processes are involved in the "fallowing" of soils.

PART I.

THE ORIGIN AND FORMATION OF SOILS.

CHAPTER I.

THE PHYSICAL PROCESSES OF SOIL FORMATION.

SINCE the physical and mechanical effects of the agencies mentioned above usually precede, in time, the chemical changes, which are materially facilitated by the previous pulverization of the rocks, the former should be first considered.

Effects of heat and cold on rocks.—Most rocks are aggregates of several simple minerals; a few only (limestone, quartzite and a few others) expand or contract alike in all their parts. Of the minerals composing the compound rocks, scarcely any expand to exactly the same extent under the influence of the sun's heat, especially when their colors differ; nor, in the great majority of cases, does one and the same mineral expand alike in all three directions. It follows that at each change of temperature there is a tendency to the formation of minute fissures between adjacent crystals or masses of different simple minerals; and especially in the case of large crystals of certain kinds, this action alone will gradually result in the disruption of the rock surface, so that individual crystals may be detached with little difficulty. In any case, the cracks so formed are gradually widened by a frequent repetition of the changes of temperature, coupled wih access of air, water, dust, and the rootlets of plants; all of which brings about a gradually increasing rate of surface crumbling. This is especially conspicuous at the higher elevations of mountains, where the temperature changes are very great and abrupt; and also in the clear atmosphere of deserts, where owing to the extent and suddenness of temperature- changes between day and night, caused by the free radiation of heat into the clear sky, even homogeneous pebbles are known to be almost explosively disrupted in the mornings and evenings of clear days.

Such effects may often be strikingly observed on small surfaces of compound crystalline rocks, such as granite, exposed on glaciers, where the daily changes of temperature are often extreme, viz., from below the freezing point to as much as 130 degrees Fahr. (54.4 degrees C.). In such cases one may sometimes scoop off the disintegrated rock by the handful, while yet the mineral surfaces are almost perfectly fresh.

On a larger scale, the disruption and scaling off of huge slabs of granite, and rocks of similar structure, may be observed in southern California on the southwestern side of rock exposures, where slabs from a few inches to ten and more feet in length and eight or ten inches thick, have slid off, perhaps still leaning against the parent rock, which has been rounded off by a succession of such events into the domelike form so characteristic of granite mountains. Merrill[1] reports similar exfoliations to occur especially on the peninsula of California, on Stone Mountain in Georgia, and elsewhere.

A striking exemplification of the effects of frequent and rapid changes of temperature on rocks, and of humid and dry climates as well, is seen in the case of the great monoliths of Egypt, one of which now stands in the Central Park, New York. In the quarries of Syene in Upper Egypt, where most of these monoliths were obtained, the rough blocks that were in progress of quarrying when the work was abandoned, quite two thousand years ago, still show an almost perfectly fresh surface; and the same is true of the finished obelisks in Lower Egypt, where both the changes of temperature and the rainfall are somewhat greater. It is a matter of public note that one of "Cleopatra's Needles" which was set up in Central Park nearly thirty years ago, but originally erected at Heliopolis on the Nile, is in great danger of destruction from the influence of a totally different climate, in which both the temperature changes and the rainfall are much more frequent and severe than in Egypt. The large crystals of feldspar and quartz which compose the (syenite) rock material have had fine fissures formed between them by often-repeated expansion and contraction; which when filled with water and subsequently

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[1] See Rocks, Rock-weathering, and Soils, page 246; also paper on Domes and Dome Structure, by G. K. Gilbert, in Bulletins of the Geol. Society Am., Vol. 15, pp. 29–36.

changed to ice, the latter's expansion in freezing (see below) has still farther enlarged them and caused a scaling-off, which threatens to obliterate the hieroglyphic inscriptions. Thus temperature-changes and a rain followed by freezing may in a few days produce a greater effect than a thousand years of Egyptian climate.

Cleavage of rocks.—Many kinds of rocks have definite directions of ready cleavage. The most common and obvious cases of this kind are schists, slates and shales, cleaving readily into plates or irregular flat or lens-shaped fragments. Such structure greatly favors disintegration, especially when the layers are on edge at steep angles. But there are other apparently structureless, massive rocks, particularly basalts and other eruptive rocks related to them, as well as many sandstones and claystones, that have a strong tendency to cleave into more or less definite forms when struck; such as columns or prisms, square, six-sided or diamond-shaped blocks, etc. Similar forms are naturally produced in them under the influence of changes of temperature; by the formation of minute cracks at first, then enlargement of these by the several agencies already mentioned.

Effects of freezing water.—The irresistible force exerted by the expansion of water in freezing, amounting to about 9 per cent of its bulk, is a powerful factor in widening and deepening fissures and cracks of rocks; not uncommonly, whole masses of rock are rent into fragments by this agency, which is one of the most common causes of "rock falls" on the brink of precipices. By the freezing process cracks and crevices are enlarged, and the surfaces exposed to weathering are still farther increased; and the rock fragments or soil particles are loosened and rendered more liable to be removed from the original site, whether by gravity, wind or water.

Glaciers.—Ice in the form of the glaciers that descend from mountain chains (see figure 1), and of the moving ice sheets that have covered large portions of North America and Europe in past ages and now cover Greenland and the South Polar continent, exerts a most potent action in abrading and grinding even the hardest rocks; not so much by the direct friction of the moving ice itself, as by the cutting, scoring, grinding and crushing action which the stones imbedded in the ice, or carried and shoved by it, exert upon the rocky channels in which the ice stream moves, as well as upon each other. The product of this grinding process is largely very fine (hence "glacier flour"), so that it remains suspended in the water of the glacier-streams until their velocity is permanently checked when reaching a plain or lake. This suspended stone-flour imparts to the glacier streams their distinctive character of "white rivers," as contradistinguished from the clear, dark "green rivers" that have their origin outside of glaciated areas. This difference can be readily observed in traveling along any of the glacier-bearing mountain chains of the world, and is frequently expressed in the names of the streams.

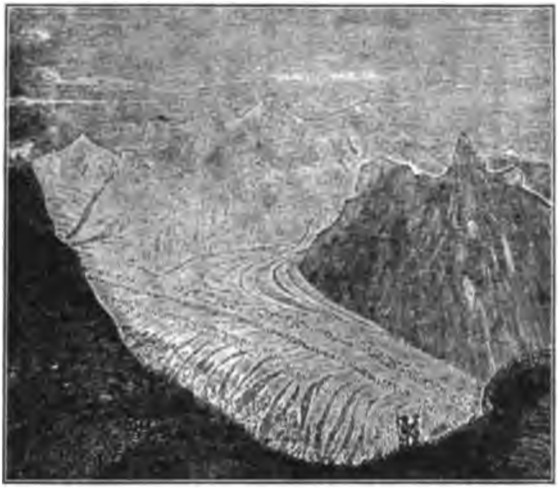

Fig. 1.—Zermatt Glacier (Agassiz).

The physical analysis of mud from the foot of Muir glacier,[1] Alaska, at its sea front, made by Professor Loughridge, shows the prevalent fineness of the materials brought down by the glacier waters.

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[1] Collected by Dr. W. E. Ritter of the University of California.

PHYSICAL COMPOSITION OF GLACIER MUD.

MATERIAL.	DIAMETER.	PER CENT.	
Clay	?	16.57	70.31
Fine silt	.0023 — .016 mm.	53.74	
Fine silt	.016 to .025 mm.	4.38	
Medium silt	.025 to .036 mm.	7.06	
Coarse silt	.036 to .047 mm.	5.91	
Coarse silt	.047 to .072 mm.	3.76	
Fine sand	.072 to .12 mm.	1.14	
Medium sand	.12 to .16 mm.	1.56	
Total		94.12	

It will be noted that over 70 per cent of this mud consists of extremely fine, wholly impalpable materials; but little of which is true clay.

The fineness of the glacier-flour renders it peculiarly suitable for the rapid conversion into soil, and such soils are usually excellent and remarkably durable. The great and lasting fertility of the soils of southern Sweden is traced directly to this mode of origin, and doubtless the great American ice sheet of glacier times is similarly concerned in the high quality of the soil of our "north central" states, from the Ohio to the Great Lakes and the Missouri.

The accumulations of rocks and debris of all sizes in the "moraines" or detrital deposits of glaciers and ice-sheets form another class of glacier-made lands which cover extensive and important agricultural areas (drift areas), both in the old and new worlds. Such lands are undulating or slightly hilly, and the soil usually contains imbedded in it stones of a great variety of kinds and sizes, partly angular, partly rounded and polished by friction. Of course the frequent and violent changes of temperature occurring on the surface of a glacier, aid materially in reducing the rocks carried by it to the condition in which we find the material of the moraines; which commonly form lateral or cross ridges in valleys formerly occupied by glaciers.

Action of flowing water.—The action of flowing water is doubtless at this time the most potent mechanical agency of soil formation. From the sculpturing of the original simple forms in which geological agencies left the earth's surface into the complex ones of modern mountain chains, to the formation of valleys, plains, and basins out of the materials so carried away, its effects are prodigious. The torrents and streams in carrying silt, sand, gravel and bowlders, according to velocity and volume, do not merely displace these materials; the rock fragments of all sizes not only score and abrade the bed of the rill or stream, but by their mutual attrition produce more or less of fine powder similar to that formed by glacier action; usually more mixed in its ingredients than the former, because derived from a wider range of drainage surface. In the glacier stream itself, it is easy to trace the gradual transition from the sharp stone fragments lying in the water as it issues from the terminal ice cave at the lower end of the glacier, to the rounded shingle found a few miles below.

FIG. 2.—Erosion of Hawaiian Hills, near Honolulu. (Phot. by H. C. Myers.)

On slopes where water flows only during rain or the melting of snow, the same erosive effects may be seen as between the heads of ravines and their outlets. (See figure 2,) It is there too that the surprisingly rapid cutting-out of channels by the aid of water charged with rock fragments or gravel, can readily be observed, and the enormous power of water erosion convincingly shown. In the United States the stupendous gorges of the Columbia and Colorado rivers, the former cut to a depth of over 2000 feet into hard basalt rock, the latter to over 5,000 feet, partly into softer materials, partly into granite, are perhaps the most striking examples of this power; the manifestations of which can, however, be as convincingly seen in thousands of minor rivers and streams.

All the materials so carried off from the higher slopes are finally deposited on a lower level; whether only a short distance away on a lower slope (colluvial soils), or farther away in the flood plain of streams, rivers, or lakes (alluvial soils). Other things being equal, the finest materials are of course, carried farthest, and often into the sea; in which, however, they cannot long remain suspended, but are quickly thrown down, forming river bars, flood plains, and deltas. The fineness of the material of delta soils, like that of those made from glacier flour, insures them the same advantage, viz. great fertility and durability.

It is calculated that the Mississippi River carries into the Gulf of Mexico annually some 7469 millions of cubic feet of earthy deposits, which would fill one square mile of surface to the height of 268 feet, or would cover that number of square miles to the depth of one foot.

FIG. 3.—Cliffs and caves on sea-beach at La Jolla, Calif, showing effects of Wave action.

Wave-Action.—The powerful effects of the beating of waves upon abrupt shores of seas or lakes are in evidence all over the world, and these effects are so characteristic that they can be recognized even where no sea or lake exists at present. Gravel and sand are carried in the surf and serve as grinding materials, wearing even the hardest rocks into grooves, rills, channels and caves, defining sharply the varying degrees of hardness or tough resistance in different parts of rocky cliffs; frequently undermining them and causing extensive rock-falls. The latter then serve for a time to break the violence of the waves' onset, and may even cause permanent shore deposits to be formed under their lee.

Such deposits are very generally formed on gently sloping beaches, and as the water gradually recedes, sometimes by elevation of the ground, beach lines or beach-terraces are left, which indicate the successive levels of the lake or sea. Such old beach lines or terraces and level-surfaced " buttes " in the Great Basin country, and " bench lands " elsewhere, show in their structure the characteristic lines of wave-deposition.

Effects of Winds.—The action of winds in transporting soil particles (dust and sand) is familiar; and the accumulations that may be formed under the influence of regular, continuous winds are sufficiently obvious on lee shores having sandy beaches, inland of which the formation of sand dunes at times assumes a threatening magnitude. Where winds are irregular, frequently reversing their direction, of course the local effects will be less obvious, and the transportation of material actually occurring will often not be noticed. Yet there can be no doubt of the importance of wind action in soil formation, and there are cases in which no other agency can explain the facts observed over widely extended areas. This is especially true with regard to the soil masses of the high plains or plateaus of the dry continental interiors, where not only the regularity of the prevailing winds, but also the structure (or absence of structure) and pulverulent character of the soil itself, renders this the only rational mode of accounting for its presence where we find it.

The effects that may be exerted by regular winds are well illustrated in the plains and deserts of Africa as well as those of central Asia. Here we find a distinct subdivision of the desert (rainless) areas into the *stony*, from which the wind has swept all but the bedrock and gravel and where scarcely any natural growth, and certainly no cultivation is possible in the almost total absence of soil. The next subdivision is the *sandy* desert, to leeward of the stony area, where the winds are less violent and regular, and where, therefore, the sand has been dropped and is wafted back and forth by "sand storms," the surface being covered with moving sand dunes. Still farther to leeward we find the region in which the finer portions of the desert surface has been deposited; here we have "*dust* storms" so long as the land is not irrigated; but the application of water renders the soil abundantly fruitful. Such is the case of the Oases and fertile border-lands of the Sahara and Libyan deserts.

In the cultivated portions of the Mojave and Colorado deserts in California, plowing of the land during a dry time is not uncommonly followed by a bodily removal of the loosened soil to neighboring fields, sometimes leaving a gravel surface behind. Such "blown-out lands" exist naturally at numerous points in the Colorado desert.

Sven Hedin (Central Asia and Tibet, Vol. II,) shows that from the effects of the violent storms that prevail in the Gobi or Takla Makan desert, Lop-nor lake, the sink of the Tarim river, has in the course of time shifted its bed as much as fifty miles in consequence of the excavation of the southern part of the desert by the wind; while the sand so blown out, together with the deposits from the rivers, now tends to fill up the present (southern) lake, which is gradually returning northward toward its original site, now a desert, but around which formerly a dense population existed.

The great plains of North America, the pampas of South America, the plateaus of Mongolia and especially the fertile loess region of northwestern China, are also cases in point. The dense dust storms of these regions are familiar and unpleasant phenomena, which are often observed even by vessels at sea off the east coast of South America, where the dust-laden "pamperos" at times compel them to proceed with the same precautions as in a fog; and the same is true of the northeast winds blowing off the Sahara desert on the west coast of Africa.

The effects of windstorms carrying sand in the *erosion of rocks* are very obvious and striking in many parts of the world; nowhere probably as much so as on the great plains of western North America, where the geological composition of the "bad lands" is frequently impressed upon the rock surfaces very prominently. The strikingly grotesque forms are frequently brought out in this way, especially in the case of "mushroom" rocks, where a hard stratum has remained as a covering while softer layers underneath have been worn away. The illustration annexed shows such a case on the plains of Wyoming as figured in the Report of the U. S. Geological Survey, on the Central Great Plains, by N. H. Darton. Striking examples of the same effects are seen on the shores of Lake Michigan in the Grand Traverse region, where the rocky cliffs are visibly worn away and carved under the influence of the regular "sand-blasts" of northwest winds. On a smaller scale the effects of these sand-blasts may be noted in the cobble-deserts, where we frequently find the cobbles worn away on the windward side in a very characteristic manner; the lee side remaining rounded and smooth, while the structure of the rock is strongly outlined on the windward side.

FIG. 4.—"Mushroom rocks," produced by Wind action, Wyoming. (Darton.)

CLASSIFICATION OF SOILS.

The physical Constituents of soils are thus, in the most general terms, first, *rock powder* ("sand") more or less changed by weathering; second, *clay*, as one of the chief results of the weathering process of silicate minerals; and thirdly, ***humus***, the dark-colored remnant of vegetable decay. According to the obvious predominance of one or the other of these primary ingredients, soils are popularly, in the most general sense, classed as "heavy" and "light"; the former term corresponding as a rule to those in which clay forms a prominent ingredient, while sandy and humous or "mold" soils usually fall under the latter designation, because of their easy tillage. For practical purposes these subdivisions are both convenient and important, and they form the ordinary basis of land classification. Beyond these, the degree of fineness of the rock debris, and their physical and chemical constitution, determine distinctions such as gravelly, sandy, silty, loamy, calcareous, siliceous, magnesian, ferruginous, and others of less general application, though locally often of considerable importance.

For the purposes of discussion and definition, however, another basis of classification is needed, which essentially concerns both the origin and the adaptations of lands.

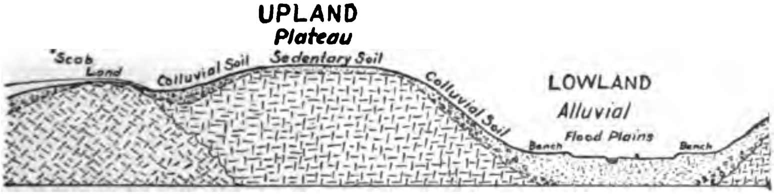

Fig. 5.—Diagram illustrating the genetic relation of different soil classes to each other.

1. *Sedentary Soils.*—When soils have been formed without removal from the site of the original rock, by simple weathering, they are designated as *sedentary*, or *residual* soils, or "soils in place." In the case of these, the original rock underlies the soil or subsoil at a greater or less depth, according to the intensity and duration of the weathering process, and is usually more or less softened and decomposed at the surface where it meets the soil layer. The latter of course bears some of the distinctive characters of the parent rock, and its composition and adaptations may, in a measure, be directly inferred from that origin. Such soils usually contain, especially in their lower portions, some angular fragments of the parent rock. In

some cases sedentary soils may have been partially derived from rocks that have been removed from above the present country rock by erosion, and in that case fragments of such vanished rock may also be present.

Sedentary soils are most commonly found on rock plateaus and on slopes or plains underlaid by rock strata of but slight inclination, where the velocity of the " run-off " rainfall is not sufficient to dislodge the rock debris. Extended areas of such soils exist in the granitic areas of the southern Alleghanies, in the " black prairies " of the Cotton States, and on the " basaltic " plateaus of the Pacific Northwest.

2. *Colluvial Soils.*—When the soil mass formed by weathering has been removed from the original site to such a degree as to cause it to intermingle with the materials of other rocks or layers, as is usually the case on hillsides, and in undulating uplands generally, as the result of rolling or sliding down, washing of rains, sweeping of wind, etc., the mixed soil, which will usually be found to contain angular fragments of various rocks, and is destitute of any definite structure, is designated as a *colluvial*[1] one. Colluvial soil masses are frequently subject to disturbance from landslides, which are usually the result of water penetrating underneath, between the soil mass and the underlying rock, or sometimes simply of complete saturation of the former with water. Aside from such catastrophic action, they commonly have a slow downward movement in mass (creep), which ordinarily becomes perceptible only in the course of years; most quickly where there are heavy frosts in winter, which act both by direct expansion, and by the state of extreme looseness in which the soil mass is left on thawing. Colluvial soils form a large portion of rolling and hilly uplands, and are of very varying degrees of productiveness.

3. *Alluvial Soils.*—When soils are the result of deposition by streams, the material having been gathered along the course

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[1] The term "overplaced," used for such soils in late memoirs of the U. S. Geological Survey, is at least superfluous, in view of the perfectly understood term already in general use, and does not seem to commend itself for adoption by any special or superior fitness; nor does the suggestion of Shaler (The Origin and Nature of Soils, 12th Rep. U. S. Geol. Survey) to include the colluvial soils within the alluvial class, commend itself either from a theoretical or practical point of of view, since but few useful generalizations can apply to both classes.

of the stream from various sources and carried to a distance before being deposited, the soil is designated as *alluvial.* These are the soils of the valleys, flood-plains, and sea- and lake-borders, past and present. Being of mixed origin, their general character may vary from one extreme to the other, both as regards physical and chemical composition. Since, moreover, they represent the finer portions of the soils of the regions drained by the watercourses, alluvial soils are as a rule of a fine texture; and as representing the most advanced decomposition products of the parent rocks, they are usually preëminently fertile. This is proverbially true of the flood-plains of rivers, and still more of their deltas—the bodies of lands formed near their outlets into seas or lakes.

Character of these soil-classes.—Sedentary soils are as a matter of course, other things being equal, dependent entirely on the parent rock for their specific character; and taking into consideration the various rocks (usually one or few) from which they may have been derived, nearly the same is true of *colluvial* soils, except that a portion of the clay and finest pulverulent matters may in their case be carried down on the lower slopes and into the valleys and streams, by the hillside rills.

According to the calculation of Merrill (*Rocks, Rock-weathering, and Soils*, p. 188) granite when transformed into soil *without loss* would increase in weight by 88 %; more than doubling its bulk. More usually, the leaching process *diminishes* their volume as compared with the parent rock.

Alluvial soils are also of course to a certain extent dependent upon the character of the rocks and surface deposits occurring within the drainage area of the depositing stream. As a rule their composition is much more generalized; but their character as to the relative proportions of sand and clay is essentially dependent upon the velocity of the water current. Thus in the upper portions of valleys, where the slope is relatively steep and the velocity therefore high, a large proportion of cobbles and gravel is often present in the deposits, sometimes to the extent of rendering cultivation impracticable, or at least unprofitable. As the slope and velocity decrease, first coarse and then fine sand will be the prominent component of the deposited soil; while still lower down, in the region of slack water, the finest sand or silt, together with clay, will predominate. According to Hopkins,[1] flowing water will, at a velocity of three inches per second, *carry* in suspension only fine clay (and silt); at eight inches it will carry sand as large as linseed. At one and one-third inches, it will *move* pebbles one inch in diameter; and at a velocity of two ~~inches~~ per second, pebbles of egg size are moved along the stream bed. Since the velocity of streams subject to freshets will vary greatly from time to time, deposits of very different grain will in such cases be found alternating with one another in the soil stratum of the flood plain. In fact, this alternation and the more or less stratified structure resulting therefrom, is the distinguishing mark of alluvial soils as such. It is true that this peculiarity is also sometimes found in the case of lands now lying far above the flood-plains of present rivers; but this is due to the elevation of the land or the depression of the river channels at a former period, prior to which such lands (commonly known as river terraces, benches or second bottoms) were formed. The same is true of lake terraces (" mesas "), which cover enormous areas in some parts of the world, more particularly in western North America. It must nevertheless be remembered that such alluvial terrace or bench soils differ in some respects from the modern alluvials, on account of their long exposure to atmospheric action alone; one result of which is that they are usually much poorer in humus, and therefore of lighter tints, than the more modern soils of alluvial origin. Other differences will be adverted to hereafter.

As a matter of course the above distinctions, especially between colluvial and alluvial soils, cannot be rigorously maintained in all cases. There are transitions from one class to the other, so that it is sometimes optional with the observer to which of the two classes a particular soil may be considered as belonging. On the lower slopes of the hills bordering alluvial valleys the colluvial slope-soil may often be found alternating with the alluvial deposits, or bodily

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[1] Geikie, " Text-book of Geology, 3d ed.

washed away to be redeposited as alluvium at a greater or less distance.

One characteristic of the flood-plain lands of all the larger rivers, and more or less of all streams subject to periodic overflows, is that the land immediately adjoining the banks is both higher and more sandy than are the lands farther back from the stream. The cause of this phenomenon is that as lateral overflow diminishes the velocity of that flow, its coarser portions are deposited near the river banks, while the finer particles are carried farther away, until finally only the finest —clay-substance—reach the lagoons or lakes filled with the overflow or back-water, and are there in the course of time deposited as heavy clay "swamp" soils. The same occurs where rivers empty into lakes or the sea; and these slack-water or delta lands are, as a rule, the most productive on the river's course. The continued productiveness of alluvial soils is moreover in many cases assured by the deposition, during overflows, of fresh soil-material brought down from the head waters of the streams. The Nile, and the Colorado river of the West, illustrate this point.

Lowering of the land-surface by soil formation.—It is evident that the soil-forming agencies must in the course of time materially affect both the surface conformation and the absolute level of the land. The sharp pinnacles and crests of rock are abraded into the rounded forms now characterizing our uplands and lower ranges of hills and mountains; and it is estimated that, *e. g.*, the general level of the drainage basin of the Mississippi river is lowered about one foot in 7,000 years, the material being carried into the lowlands and the sea.

CHAPTER II.

THE CHEMICAL PROCESSES OF SOIL FORMATION.

Chemical Disintegration, or Decomposition.

It may be said that in general, the physical agencies of disintegration are most intensely active in the dry or arid regions of the globe, while chemical processes of decomposition are most active in humid climates.

The chemical decomposition of rocks is primarily due to the action of the atmosphere, the average composition of which may be stated as follows:

	VOLUME PER CENT.	WEIGHT PER CENT.
Nitrogen	78.00	75·55
Oxygen	21.00	23.22
Carbonic dioxid	03–.04	.045–.060
Ammonia	1 to 4 millionths	
Water vapor	Variable; 48 to 83 grams per cubic meter, when saturated between 0° and 50°C.	

In addition to the above, air contains minute amounts of the very indifferent and therefore practically negligible elements, argon, krypton, neon, xenon and helium, the aggregate amount of which in air is somewhat less than one per cent, of which the greater part is argon. So far as known these elements take no part whatever in vegetable or animal life, and possess no known chemical action or affinity.

The primary active agents in effecting chemical changes in rocks by which soils are formed, are water, carbonic acid,[1] and oxygen; all therefore ingredients of the atmosphere. Hence the chemical changes so brought about are in the most general sense comprehended within the term weathering, as

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[1] Owing to the universal presence of water (H_2O) in air as well as in soils, it is usual and convenient to speak of carbonic dioxid (CO_2) gas when so occurring as carbonic acid (H_2CO_3), of which it produces the effects ($CO_2+H_2O=H_2CO_3$).

applied to rocks; while the corresponding but more complex action within the soil itself is usually termed fallowing.

Effects of Water.—Since but few substances, particularly among those forming rocks, are totally insoluble even in pure water,[1] and some (such as gypsum) may be considered easily soluble in the same, the rain water must exert solvent action wherever it penetrates. In nature, however, strictly pure water does not occur, it being difficult to obtain it even artificially. Among the "impurities" almost always contained in natural water, there are several that materially increase its solvent power. Foremost among these, both because almost universally present and on account of its great ultimate efficacy, is

Carbonic dioxid, in contact with water forming *carbonic acid,* the acidulous ingredient of all effervescent waters, the gas which is produced in nature by innumerable processes, such as decay, putrefaction, fermentation; the slow or rapid combustion of vegetable and animal substances, such as wood, charcoal and all other fuels; by the respiration of animals; in the burning of limestone, etc. It is therefore of necessity contained in air, on an average to the extent of about 1-3000 of its bulk in the general atmosphere, but locally in considerably higher proportions because of proximity to sources of formation, and of its greater density as compared with air (1½ as against 1). It may thus accumulate in inhabited buildings, in cellars, wells, mines, caves; and it is contained in considerable proportion in the air of the soil. Moreover, being easily soluble in water (to the extent of an equal volume at the ordinary temperature and barometric pressure) it is contained in all natural water, whether of rains, rivers, springs or wells, and largely of course in that percolating the soil. Such waters may therefore be considered as being acid solvents; and as such, they exercise a far more energetic and far-reaching effect than would pure water.

Carbonated water a universal solvent.—While limestones are the rocks most obviously acted upon by carbonated water, few if any resist it altogether. Even quartz rocks of the ordinary kinds are attacked by it; only the purest white crystalline quartzite may be considered as sensibly proof against it.

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[1] See Chapter 18.

Granite and the rocks related to it are rather quickly acted upon, because of the presence of the feldspar minerals containing potash, soda and lime as bases[1] together with alumina.

The results of this action are highly important; one being the formation of clay, so essential as a physical ingredient of soils; the other the setting-free of potash, one of the most essential nutrients of plants. Hornblende and the related minerals are similarly acted upon so far as they contain the same substances. In all cases, of course, the silica (silicic acid) set free by the carbonic acid remains partially or wholly in the resulting soils, as such. Lime also at first mostly remains behind in the form of the carbonate; but potash and especially soda compounds, being mostly readily soluble in water, are largely carried away by the latter.

The effect of carbonated water upon silicate minerals is greatly increased by the presence of ammonia (ammonic carbonate), which always exists in atmospheric water to a greater or less extent. This effect may readily be noted on the windows of stables, or other places where animal offal decays, by the dimming of the glass surfaces; also in glass bottles containing solution of ammonic carbonate.

Action of Oxygen.—The effects of atmospheric *oxygen* on rocks are of course confined to those containing substances capable of farther oxidation. Chief among these are ferrous (iron monoxid) and ferroso-ferric oxid the latter imparting bottle-green, bluish and black tints to so many minerals and rocks that these colors may usually be taken as indicating its presence. By taking up more oxygen the ferrous and ferroso-ferric oxids are converted into ferric oxid or its hydrate (rust), the tints mentioned passing thereby into brick-red or rust color, according as the former or the latter (or sometimes their intermixtures) is formed. In either case there is an increase in bulk; and this when taking place in the cracks or crevices of minerals or rocks, tends, like the freezing of water, to widen

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[1] The increase of solvent power on feldspar when carbonated instead of distilled water is used, was well exemplified in an experiment made by Headden (Bull. 65, Color. Exp't Sta., p. 29), who allowed pure distilled and carbonated water respectively to act on fresh but finely pulverized feldspar, with frequent shaking, for five days. The distilled water disolved .0081 gram, the carbonated water, .0723 gram of solids, or nearly nine times as much as the distilled water. Both residues gave strong reactions for potash with platinic chlorid.

the cracks and thus to increase the surface exposed to attack. Since ferrous compounds, when soluble in water, are injurious to plant growth, this oxidation is of no little importance, and in soils must be carefully maintained against a possible reversal.

It is hardly necessary to insist that the action of all these chemical agents continues in the soils themselves, and that owing to the fineness of the material, resulting in an enormously increased surface exposed to attack, such action acquires increased intensity. This is the more true as in soils bearing vegetation there are always superadded the effects of the humus-acids resulting from the decay of vegetable matter, as well as of the acid secretions of the living plants.

Action of Plants and their Remnants in Soil Formation.

(*a*) *Mechanical action.*—The direct action of plants in forcing their roots into the crevices of rocks and minerals and thus both widening them by wedging, and by exposing new surfaces to weathering, has already been alluded to. That the mechanical force exerted by root growth is very great, may readily be judged from their effects in forcing apart, even to rupture, the walls of rock crevices; but actual measurement has shown the force with which the root, *e. g.*, of the garden pea penetrates, to be equal to from seven to ten atmospheres, say from 200 to over 300 pounds per square inch. Such a force, exerted under the protection of the corky layer protecting the root tips, often produces surprising effects.

(*b*) *Chemical action.*—Vegetation takes a most important part, from a chemical point of view, both in the first formation of soils and in their subsequent relations to vegetable life. The lower forms of vegetation are usually the first to take possession of rock surfaces; foremost among these are the lichens. In humid climates we find these crust-like plants incrusting more or less all exposed rock surfaces, sometimes with a solid mantle that can be peeled off in wet weather, showing the corroded rock-surface, and the beginnings of soil clustering amid the root-fibrils beneath. A microscopic examination of the substance of these lichens often shows as a prominent ingredient, crystals of oxalate of lime, the lime having of course been derived from the rock, while the oxalic acid has been formed by the plant and used in the corrosion of the rock minerals. When it is remembered that this acid is comparable in strength to hydrochloric and nitric acids, the energy of the attack of the lichens is explained. Its progress can often be traced, even beyond the visible root fibers, by a change in the color of the rock; *e. g.*, from rust-color to brick red.

When by the action of the lichens a certain depth of loosened rock or half-formed soil has been produced, the next step is usually the advent of various mosses, which gradually shade out the crust-like lichens, while the erect kinds persist for some time. Eventually the mosses, after having increased still farther the soil layer on the rock surface, are themselves partially or wholly displaced by the hardier species of ferns; and with these the higher flowering plants, such as the stonecrops and saxifrages (the latter deriving their name from their "rock-breaking" effect), the heather, and many other or shallow-rooted plants, gradually take possession. The roots of all plants secrete carbonic acid; and many of them, much stronger vegetable acids, such as oxalic and citric. In the crevices of rocks we commonly find the roots forming a dense network over the surfaces, the marks of which show plainly the solvent effect produced on the rock by the root secretions. This is most readily observable on a polished marble surface, or on feldspathic rocks. Of course the progress of soil-formation is very much more rapid when, as in the case of powdered lava (volcanic ash) and rock debris resulting from the effects of frost etc., the surface is very much increased. In tropical climates, where both vegetative and chemical action is most intense, it takes some of the higher plants only a few years after a volcanic eruption to take possession of portions of the "ash" surfaces; thus helping to form a soil on which after a few more years agricultural plants such as the vine and olive yield paying returns.

To this direct action of the higher plants is always added, to a greater or less extent, that of innumerable bacteria, as well as molds; whose vegetative and secretory action materially assists that of the roots, and the weathering process in general.

Humification.—While the mechanical action of the roots and the chemical effect of the acids of their root secretions are very efficient in promoting the transformation of mere rock powder into soil material proper, the efficacy does not end with the life of the plant. In the natural process of decay to which the roots are subject after death, and which also affects the leaves, twigs and trunks falling on the surface, the vegetable matter suffers a transformation which must be considered more in detail hereafter, and results in the formation of the complex mixture of dark-tinted substances known as vegetable mold or *humus;* the remnant of vegetation that imparts to surface soils their distinctive dark tint. Its functions in soils are both numerous, and important to vegetable growth; as regards soil formation, it assists disintegration of the rock minerals both by the formation of certain fixed, soluble acids capable of acting on them with considerable energy, and by the slow but continuous evolution of carbonic acid under the influence of atmospheric oxygen, which has been alluded to above.

Causes influencing chemical action and decomposition.—The chemical processes causing rock decomposition are of course continued in the soil, and there also are materially influenced by climatic and seasonal conditions, which bring about great differences in the kind and intensity of chemical action.

Within the ordinary limits of solar temperatures it may be said that, other things being equal, the higher the temperature the more intense will be chemical action in soil formation. Since, however, water is a potent factor in the majority of these processes, the presence or absence of moisture at the same time with heat will cause material differences in the kind and intensity of chemical action. In view of the importance of carbonic acid as a chemical agent, the presence or absence of vegetable matter or humus, from which by oxidation or decay carbonic and humus-acids are formed, will likewise be of material influence.

The presumption that climatic and seasonal conditions must greatly influence both the kind and rapidity of the soil-forming processes, is fully borne out by observation and practice. Especially is the amount and distribution of rainfall of great importance in this respect, and should therefore be first considered.

INFLUENCE OF RAINFALL ON SOIL FORMATION; LEACHING OF THE LAND.

In the general consideration of the soil-forming processes, it has been stated that soils formed by the disintegration of rocks "in place," *i. e.*, without removal from the original locality, are also designated as "residual"; meaning thereby that only a portion of the original rock remains to form the soil mass, while another portion has been removed. To a slight extent this removal occurs by the partial washing-away of the finest clay and silt particles; but the most important action from the agricultural point of view is the removal by leaching with the carbonated water of the atmosphere and soil, of certain easily-soluble compounds formed in the process of chemical decomposition of rocks and resultant soils. The nature of these compounds is exemplified in the subjoined table giving the composition of some waters flowing from drains in unmanured fields, laid at depths of from two to three feet; and for comparison with these, the composition of the water of some of the world's large rivers, showing what these largest drains carry into the ocean.

The analyses have in all cases, where necessary, been recalculated to parts per million, and to oxids, from the published data.

The letter "c" indicates that the preceding figure has in the absence of a direct determination been stoichiometrically calculated from the data given, in order to complete the comparison.

COMPOSITION OF DRAINAGE WATERS FROM UNMANURED GROUND.
PARTS PER MILLION.

	ROTHAMSTED. (VOELKER.)		PROSKAU. (KROCKER.)		MOCKERN. (Ö. WOLFF.)		FARNHAM. (WAY.)		MUNICH. (ZÖLLER.)		
					Rye Field.	Meadow.	Wheat Field.	Hop Field.	Lysemeter Drainage.		Average.
Potash, K_2O	1.7	5.4	2.0	2.0	8.5	3.4	Trace.	Trace.	6.5	2.4	3.2
Soda, Na_2O	6.0	11.7	15.1	13.7	23.3	8.2	14.3	45.7	7.1	5.6	15.1
Lime, CaO	98.1	124.3	133.0	118.1	122.6	22.5	69.3	185.0	145.8	57.6	107.6
Magnesia, MgO	5.1	6.4	33.3	22.4	14.9	6.7	9.7	35.1	20.5	8.9	16.3
Iron Oxid, Fe_2O_3	5.7	4.4	6.6	6.6	8.0	6.0	5.9	7.1	.1	6.3	......
Alumina, Al_2O_3	......	......	......	......					......	......	......
Silica, SiO_2	10.9	15.4	7.0	6.0	7.0	4.0	1.35	12.1	10.4	11.3	......
Carbonic Acid, CO_2	48.1	44.4	75.8	82.6	......	121.3	......	......	......	......	......
Phos' Acid, P_2O_5	.63	9.1	Trace	Trace.	Trace.	19.0	Trace.	1.7	2.2	Trace.	0.5
Sulfuric Acid, SO_3	24.7	66.30	122.7	67.3	......	......	23.5	135.8	17.5	27.1	60.8
Chlorin, Cl	10.7	11.1	4.8	4.2	14.0	Trace.	10.0	37.4	57.5	9.5	17.7
Nitrogenas, N_2O_5	3.90	5.10	......	......	......	......	102.4	163.5	......	......	......
Nitrogenas, NH_3	.12	.13	......	......	......	......	.25	.03	......	......	......
Total Mineral Matter	215.9	295.5	400.3	322.9	198.3	191.1	248.8	623.5	267.6	128.7	......
Less O : Cl	2.35	2.4	1.1	.9	3.1	......	2.2	8.2	12.7	2.14	......
Corrected Total	213.3	293.1	399.2	322.0	195.2	191.1	246.6	615.3	254.9	126.6	285.7
Organic Matter	22.9	19.3	25.0	16.0	26.0	26.0	100.0	105.7	20.5	12.6	......
Total Solids	235.2	312.4	424.2	338.0	221.2	217.1	346.6	721.0	275.4	139.2	352.6

COMPOSITION OF RIVER WATERS. PARTS PER MILLION.

	Yukon, Alaska.	Dwina, above Archangel.	St. Lawrence, Pointe des Cascades.	Missouri, Montana.	Mississippi near Carrollton, La. Average of one year.				Rio Grande, Ft. Craig, N. M.	Nile near Cairo.		Average of these 7 Rivers.	Average of 19 Great Rivers of the World.
						Max.	Min.	May 1905.		High. Aug. 1874.	Low. May 13, 1875.		
Potash, K_2O	Trace	12.58	1.40	1.90				2.80	.80	15.01	4.04	4.80	2.40
Soda, Na_2O	8.10	23.38	6.90	30.10	19.80c			13.50	43.40	5.87	13.01	18.20	7.10
Lithia, Li_2O													.20
Lime, CaO	30.40	37.30	45.30	58.00		49.75 Dec.	33.81 Feb.	41.20	22.80	44.22	51.78	43.50	43.20
Magnesia, MgO	7.30	36.25	9.70	18.10	40.80	16.39 March	10.32 Feb.	11.30	2.10	10.33	10.29	13.10	14.70
Manganese, Mn_3O_4					12.40			.16					1.20
Ferric Oxid, Fe_2O_3		1.63		3.10				.11				1.80	2.80
Alumina, Al_2O_3	1.80				2.10			.17					3.10
Silica, SiO_2	7.60	3.05	32.60	18.90	8.70	11.45 March	5.94 April	7.40		11.29	6.71	10.80	16.40
Carbonic Acid, CO_2	33.00	54.01	68.40	65.20c	45.10			33.16 c	10.25	42.81	40.91	38.10	46.00
Phosphoric Acid, P_2O_5		.40	Trace	.22				.33				.24	.30
Nitric Acid, N_2O_5								.23				.18	3.80
Sulfuric Acid, SO_3	8.50	29.62	47.7	21.90	.13 16.10	24.72 July	8.18 Jan.	23.90	47.00	18.37	29.31	26.90	8.00
Chlorin Cl	.40	33.09	2.40	18.00c	9.60	14.50 June	6.90 Dec.	16.10	36.00	6.28	17.37	15.50	3.70
Ammonia, NH_3								.16		.043	.014		.07
Total Mineral Matter	97.10	231.31	214.40	225.42	154.73			150.52	162.35	154.223	173.434	173.12	152.97
Less O : Cl	.10	7.33	.55	4.10	2.10			3.63	8.05	1.40	4.13	3.50	.72
Corrected Totals	97.00	223.98	213.85	221.32	152.63	180.0 July	110.0 Dec.	146.89	154.30	152.823	169.304	169.62	152.25
Organic Matter													16.4
Total Solids	97.00		213.85	221.22	152.63			146.89	154.30	11.86 164.683	31.29 200.594	169.62	168.65
	F. W. Clarke, Jour. Am. Chem. Soc. Feb. 1905, p. 112.	C. Schmidt, Jahresb. d. Chemie, 1873.	T. S. Hunt, Geol. of Canada, 1863.	Traphagen, Bull. Mont. Expt. Sta. No. 190.	Porter, Rep. New Orleans Sewerage and Water Board.			Stone, U. S. Reclamation Service.	O. Loew, U. S. Geogr. Survey W of 100th Merid. Vol. 3.	Letheby, Jour. of the Khediv. Agr. Society.			John Murray, Scottish Geogr. Mag., Vol. 3, 1887.

It will be noted that in all the drain waters, lime is the ingredient most abundantly leached out, and as reference to the acids shows, mainly in the form of carbonate, also in that of sulfate. Magnesia is next in amount among the bases; next in amount is soda, largely in the form of sodium chlorid or common salt. Potash is present only in small but rather uniform amounts. Of the acids the carbonic is the most abundant, sulfuric next; chlorin and silicic acid come next, in about equal amounts. Nitric acid passes off in small, but still relatively considerable amounts.

Comparison of the drain waters with the river waters, while showing a general qualitative agreement, also shows a marked diminution of total solids (from 285.7 to 188.7; hence "soft river water"), and especially of lime (from 107.6 to 43.2), together with the carbonic acid with which it is mostly combined; indicating a deposition of lime carbonate in the river deposits or alluvial lands. There is, on the other hand, little if any general difference in the magnesia content of the two classes of waters; nearly the same is true of soda, so that these two bases really show a considerable relative increase when the diminished total is considered. Potash remains about the same all through, viz. two parts or a little more; phosphoric acid shows a fraction of one millionth; nitric acid varies greatly but is usually higher in the drain waters, sometimes showing a heavy depletion of the land by the leaching-out of this important plant food.

It has been computed by John Murray, as quoted by Russell,[1] that the volume of water flowing into the sea in one year, including all the land areas of the earth, is about 6524 cubic miles. From the average composition of river waters as given above, it would follow that nearly five billions (4,975,117,588) of tons of mineral matter are annually carried away *in solution* from the land into the sea. The amount of *sediment* carried at the same time is many times greater; in the case of the Mississippi river, it is more than five times the amount of the matter carried in solution.

Comparison of the river waters among themselves shows less of any consistent relation to climatic conditions than might have been anticipated. The waters of the arctic streams

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[1] Rivers of North America, p. 80.

Yukon and Dwina show wider differences than any two other waters in the list, unless it be the St. Lawrence, another northern stream. The Missouri and Rio Grande show by their high content of soda, chlorin and sulfuric acid their origin in arid climates, where alkali lands prevail. The water of the Nile is here represented by two analyses,[1] one showing the season when the water is "red" and of high fertilizing quality because of the sediment it brings down from the mountains of Abyssinia; the other the "green" and relatively clear water which comes from the great lakes and through the "sudd" or grassy swamp region near the junction of the Gazelle river with the Nile. Of the analyses given of the Mississippi river water, the first represents the average of a full year's observations made weekly under the auspices of the New Orleans Commission on Sewerage and Drainage, by J. L. Porter. The fourth is an analysis made of water taken at the same point in May, 1905; the analysis having been made in full by Mr. Stone, of the Reclamation Service of the U. S. Geol. Survey, the direct determination of potash and soda being in this case included. As will be seen, and might be expected, the average of the Mississippi water corresponds quite nearly to that of nineteen of the world's great rivers as given by Murray. The very great variation in the content of sulfates is evidently due to the occasional heavy influx of the gypseous waters of the Washita and Red rivers when in flood; while the minimum content (in January) agrees almost precisely with the general average. Murray's table would hardly be changed if these analyses of Mississippi water were incorporated therein, owing doubtless to the large and varied drainage area of the great river.

Sea Water.—The nature of the substances permanently

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[1] The correctness of Letheby's analyses has been disputed, partly because of their disagreement with former analyses in the very high amount of lime, partly because of the high potash-content in the Low-Nile water. The lime content is, however, confirmed by the partial analyses made by Mathey in 1887, which gives an average of 44.1 for the year, while the older analyses, made in Europe, of *transported* water gave only half as much. Letheby working on the spot was doubtless more nearly right in this respect. His figure for potash in the "Low-Nile" water agrees with former determinations, but that in the "High-Nile" is approached only by that in the Dwina water. It may be suspected that the soda is too low and potash too high in this analysis.

leached out is also seen by considering the composition of sea water, since the ocean is the final reservoir for all the leachings of the land. It might be objected that the ocean may have received its salts from other sources; but this objection is overborne by the fact that substantially the same salts are found in landlocked lakes, in which, as they have no outflow, the leachings of the adjacent regions are perforce, as a rule, the only possible source of the salts. It is true that the nature of the salts differs somewhat in different lakes, as might be expected; but a general statement of that nature will, after all, be the same as that made in regard to sea-water. The following table of the average composition of sea-water, according to Regnault, illustrates these facts.

MEAN COMPOSITION OF SEA-WATER.

Sodium Chlorid (common salt)	2.700
Potassium chlorid	.070
Calcium sulfate (gypsum)	.140
Magnesium sulfate (Epsom salt)	.230
Magnesium chlorid (bittern)	.360
Magnesium bromid	.002
Calcium carbonate (limestone)	.003
Water (and loss in analysis)	96.495
	100.000

The average saline contents of sea-water would thus be 3.505 per cent. In twenty-one determinations of the saline contents of the Atlantic Ocean, the percentage ranged from 3.506 to 3.710 per cent. Of this mineral residue, common salt constitutes from about 75 to over 80 per cent.

We see that most prominent among the ingredients mentioned here is common salt (sodium chlorid), which forms nearly four-fifths of the total solid contents. Next in quantity are the compounds of magnesium, viz. Epsom salt and bittern, with a very small amount of the bromin compound. Next come the compounds of calcium (lime), of which gypsum is the more abundant, while the carbonate, so abundant on the land surface in the various forms of limestone, is present in minute amounts only, yet enough to supply the substance needed for the shells of shellfish, corals, etc. Least in amount of the metallic elements mentioned is potassium. Calculating the total amounts of chlorin, we find that it exceeds in weight any one other element present in the salts of sea-water, being two-sevenths of the whole solids.

Substantially the same result, with variations due to local causes, as exemplified in the varying composition of river and drain waters, is obtained when we consider the saline ingredients of lakes having no outlet, and in which therefore, the leachings of the tributary land area have accumulated for ages. The Great Salt Lake of Utah, the land-locked lakes of the Nevada basin, of California, Oregon, and of the deserts of Asia, Africa, and Australia, all tell the same tale, which may be summarized in the statement that the chlorids of sodium and magnesium, and the sulfates of sodium, magnesium and calcium constitute the bulk of the leachings of the land; while of other substances potassium alone is present in relatively considerable amount.

While the above analysis shows the ingredients of sea-water so far as they can at present be directly determined by chemical analysis, yet the presence of many others is demonstrable, directly or indirectly, from various sources. One is, the mother-waters from the making of sea-salt, in which such substances accumulate so as to become ascertainable by chemical means, and even become industrially available in the cases of potash and bromin. Another is the ash of seaweeds, which is indisputably derived from the sea-water, and contains, among other substances not directly demonstrable in the original water, notable quantities of iodin (of which this ash is a commercial source), iron, manganese, and phosphoric acid. Again, the copper sheathing of vessels, as it is gradually corroded, becomes more or less rich in silver, manifestly thrown down from the sea-water, and the silver so obtained is associated with minute amounts of gold. Copper, lithium, and fluorin likewise have been found in sea water; and it is probable that close search would detect very many of the other chemical elements as ordinary ingredients in minute amounts. This is what must be expected from the fact that few mineral substances known to us are entirely insoluble in pure water, and still fewer in water charged with carbonic acid. The latter is always present in sea-water and holds the lime carbonate in solution; on evaporation or boiling, this substance is the first to be precipitated; and thin sheets of limestone from this source are commonly found at the base of rock-salt beds, which, themselves, are evidently the result of the evaporation of segregated bodies of sea-water in past geological ages.

Summing up the facts concerning the water of the sea and of landlocked lakes, with reference to the ingredients of soils needful for the nutrition of plants, it appears that the rock-ingredients leached out in the largest amounts (lime alone excepted) are those of which the smallest quantities only are required by most plants; while of those specially needful for plant nutrition, only potash is removed in practically appreciable amounts by the stream drainage.

Result of insufficient Rainfall; Alkali Soils.—When the rainfall is either in total quantity, or in consequence of its distribution in time, insufficient to effect this leaching, the substances that otherwise would have passed into the drainage and the sea are wholly or partially retained in the soil; and when the rainfall deficiency exceeds a certain point, the salts thus retained may become apparent on the surface in the form of saline efflorescences, or as it is usually termed in North America, "alkali."[1] Their continued presence modifies in various ways the process of soil formation and the nature of the soils as compared with those of regions of abundant rainfall ("humid climates"); one of the most prominent and important results being that, besides the easily soluble salts mentioned above, the *carbonate of lime* formed in the process of decomposition is also retained, and imparts to the soils of regions of deficient rainfall ("arid climates") the almost invariable character of *calcareous* lands. There is thus in the United States a marked and practically very important contrast between the soils of the arid region west of the Rocky Mountains and those of the "humid" region between the immediate valley of the Mississippi and the Atlantic coast. These differences and their practical bearings can be best discussed after first considering more in detail the chemical decomposition of the several soil-forming minerals.

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[1] In some cases the soluble salts originate in rocks impregnated with salts from marine lagoons or landlocked lakes, or directly from their evaporation residues. But this is the exception rather than the rule.

CHAPTER III.

THE MAJOR SOIL-FORMING MINERALS.

Since the several stratified rocks, such as sandstones, shales, claystones, clays, limestones, etc., are themselves but the outcome of the same disintegrating and decomposing influences upon the crystalline rocks by which soils are now formed, we must study the action of these influences upon the minerals composing the latter rocks in order to gain a comprehensive understanding of the subject. While the number of different minerals known to science is very large, such study need not go beyond a small number of the chiefly important, rock-forming species which are so generally distributed as to require consideration in this connection. These minerals are the following: Quartz and its varieties; the several feldspars; hornblende and augite; the micas; talc and serpentine. Calcite, gypsum and dolomite, though not contained in the older rocks, must be considered because of their forming large rock deposits by themselves; and zeolites require mention because, though rarely forming a large proportion of rocks, they are of special importance as soil ingredients.

Quartz and the minerals allied to it consist essentially of dioxid of silicon, usually without (quartz proper) but partly also with water in combination (opal and its varieties). *Silicon* is next to oxygen the most abundant element found on the earth's surface. It occurs largely in the various forms of quartz, alone, or as one ingredient of compound rock-masses; the rest, in combination (as silica) with various metallic oxids, forms the important group of silicate minerals, constituting the bulk of most rocks.

Quartz occurs frequently in crystals (rock crystal; six-sided prisms terminated by six-sided pyramids), clear or variously colored; but more abundantly as quartz rock or quartzite, readily known by its hardness, so as to strike fire with steel, and by its glass-like, irregular fracture. Besides the crystalline quartz rock we find close-grained and at least partly non-crystalline varieties, such as hornstone and flint. Sandstones most commonly consist of grains of quartz cemented by some other mineral, or by silica itself; in the latter case the siliceous sandstone frequently passes insensibly into true quartzite. The loose sand so well known to common life is prevalently composed of quartz grains, whose hardness and resistance to weathering enables them to survive longest the soil-forming agencies.

Quartz and its allied rocks—jasper, hornstone, siliceous schist, etc., are all, as already stated, acted on with difficulty by the " weathering " agencies. Crystalline quartz rock may be considered as practically refractory against all but the mechanical agencies, and hence remains in the form of sand and gravel, more or less rounded by attrition, as a prominent component of most soils; sometimes to the extent of over 92 per cent. even in soils highly esteemed in cultivation, especially in the arid region. Such soils are mostly the result of the disintegration of sandstones, the cement of which has been dissolved out in the course of weathering; or they may be derived directly from geological deposits of more or less loose and unconsolidated sand. Among crystalline rocks, granites, gneiss and mica-schists are those most usually concerned in the formation of sandy soils; since in common parlance, quartz is understood to be the substance of the sand unless otherwise stated. The exceptions are especially important in the regions of deficient rainfall.

But while crystalline quartz is practically insoluble in all natural solvents, the same is not true of the jaspers and hornstones. These consist of a mixture of crystalline and amorphous (non-crystalline) silica, which is more readily soluble than the crystalline, and is attacked by many natural waters, especially by those containing even very small amounts of the carbonates of potash or soda. We thus often find that hornstone and jasper pebbles buried in the soil, while still hard internally, have externally been converted into a friable, almost chalky substance, consisting of crystalline quartz from which the cementing amorphous silex has been removed by the soil water. In the course of time such pebbles may be completely destroyed by this process, so as to be light and chalky throughout, and readily crushed in tillage. The change is the more striking when, as frequently happens, the hornstone pebble is traversed by small veins of crystalline quartz, which remain as a skeleton.

Solubility of Silica in Water.—It is easily shown experimentally that the compound of silica with water (hydrate) is under certain conditions readily soluble not only in pure water, but also in such as contains carbonic acid. It thus occurs in nearly all spring and well waters; some hot springs deposit large masses of it (sinter); and geological evidence clearly demonstrates that quartz veins have as rule been formed from water-solutions of silica.

That silica in its soluble form circulates freely in the soil water, is abundantly evident from the large amounts of it which are secreted on the outside of the stems of grasses, horsetail rushes and other plants, imparting a gritty roughness to their outer surface. In the case of the giant bamboo grass of Asia, the silica accumulated on the outside of the joints forms a hard sheath of considerable thickness, known to commerce as tabashir.

That among the first products of rock decomposition we often find small amounts of the silicates of the alkalies (potash and soda) has already been mentioned. It cannot be doubted that the same continues to be formed in soil containing the proper minerals; and there they also take part in the formation of the easily decomposable hydrous silicates designated as *zeolites,* which are largely instrumental in retaining the " reserve " of mineral plant-food in soils.

SILICATE MINERALS.

Silica occurs in nature combined with the oxids of most metals, forming silicates; but most abundantly with the earths (lime, magnesia, alumina) and alkalies (potash and soda). These compounds are the most important in soil formation; and among them the following are the chief:

The *Feldspars,* which may be defined as compounds of silicates of potash, soda or lime (either or all) with silicate of alumina. They are prominent ingredients of most crystalline rocks; potash feldspar (orthoclase) with quartz and mica forms granite and gneiss; feldspars containing soda and lime (either or both) form part of many other crystalline rocks, such as basalt, diabase, diorite, gabbro and most lavas. The feldspars are decomposed by weathering rather readily, and are important in being the chief source of clays as well as of potash in soils. When acted upon by carbonated water, the bases potash, soda, and lime or carbonates, the silica being mostly displaced; while the silicate of alumina takes up water and forms *kaolinite*, the essential basis of clays, and one of the most important constituents of soils; imparting to them the necessary firmness and cohesion, together with other important physical properties, discussed more in detail hereafter.

While thus on the one hand feldspars are the source of clay, on the other they supply one of the most essential ingredients of plant food, viz. potash; which is first dissolved by the water in the forms of carbonate and silicate, but in most cases soon becomes fixed in the soil by forming more complex (zeolitic) combinations. The soda not being retained by the soil as strongly as is potash is washed through into the country drainage; while if lime is present, it mostly remains in the form of the carbonate.

Orthoclase feldspar contains nearly 17% of potash; Leucite, a related mineral occurring in some lavas, contains 21.5%. The other feldspars contain only a few per cent, sometimes none.

Other silicate minerals, so far as they contain the same bases, are acted upon similarly to the feldspars.

In the decomposition of the feldspars by carbonated water, the compounds of potash and soda so formed are soluble in water, those of lime and magnesia are insoluble or nearly so. Hence pure clays can be formed only in the decomposition of the potash- and soda-feldspars (orthoclase, albite) while in the case of lime feldspar (labradorite) and the mixed feldspars (plagioclase, anorthite) calcareous clays (marls) are the result. Lime feldspar resists decomposition more tenaciously than do those containing large proportions of the strong bases potash and soda; potash feldspar especially is attacked most readily, and is the main source of the formation of the valuable deposits of porcelain earth or *kaolin*, which is essentially a mixture of kaolinite with fine silex and more or less of undecomposed feldspar, and is of a chalky texture.

Formation of Clays.—When instead of remaining in place, this kaolin is washed away and triturated in the transportation by water, it is partially changed from its original chalky condition to that plastic and adhesive form which is the characteristic ingredient of all clays. The remarkable properties of this substance and the part it plays in the physical constitution of soils, will be discussed in another chapter. Its lightness and extreme fineness of grain (if grain it can be called) cause it to be carried farther on by the streams than any other portion of the products of rock-decomposition save those actually in solution; it can therefore be deposited only in water that is almost or quite still (as in swamps) so long as the latter is fresh. So soon however as brackish or salt water is encountered, clay promptly gathers into floccules ("flocculates"), and thus enveloping the finest-grained silts that may have been carried along with it, it quickly settles down, forming the "mud banks" and heavy clay soils that are so characteristic of the lower deltas of rivers, as well as of swamps formed by the backwater or overflow of the same.

When instead of potash feldspar alone, the lime- or soda-lime feldspars are also concerned in the decomposition process, the resulting clay soils will be more or less calcareous, while the soda, as stated above, is for the greater part leached out permanently.

Hornblende (Amphibole) and *Pyroxene* (Augite). These are two very widely diffused minerals, differing but little in composition though somewhat differently crystallized, mostly in short columnar forms. The typical and most abundant varieties of these minerals appear black to the eye, though in thin sections they are bottle-green; they form the black ingredient of most rocks.

The color is due to ferroso-ferric (magnetic) oxid of iron; the mineral as a whole may be considered as a silicate of lime, magnesia, alumina and iron, varying greatly in their absolute proportions; alumina and iron being sometimes almost absent. When iron is lacking the mineral may be almost white (tremolite, asbestos), and its weathering is then much retarded, since the oxygen of the air cannot take part in the process of disintegration.

The black variety of hornblende is not only the most abundant as a rock-ingredient, but it also the one most easily decomposed and therefore most commonly concerned in soil formation. The black hornblende owes its easy decomposition under the atmospheric influences to two properties; one, its easy cleavage, whereby cracks are readily formed and extended by the agencies already mentioned (pp. 1–3). The other is its large content of ferrous silicate (silicate of iron protoxide), whereby it is liable to attack from atmospheric oxygen; the latter forms ferric hydrate (iron rust) out of the protoxide, thus causing an increase of bulk which tends to split the masses of the mineral in several directions, while the silex is set free. At the same time the carbonic acid of the air converts the silicate of lime and magnesia, which forms the rest of the mineral, into carbonates; and the alumina present forms kaolinite, as in the case of the feldspars. There is thus formed from this mineral, when alone, a strongly rust-colored, more or less calcareous and magnesian clay, constituting the material for rather light-textured "red" soils. In most cases however the hornblende is associated in the rock itself with the several feldspars, (mostly lime- and soda-lime feldspars) as well as with more or less quartz. The rust-colored soils are therefore most commonly the joint result of the weathering of these several minerals. This is well exemplified in the case of the "red" soils formed from the so-called granites and slates of the western slope of the Sierra Nevada of California.

Pyroxene or Augite so nearly resembles hornblende in its chemical composition and crystalline form, that what is said of the latter may be considered as applying to augite also. Owing however to the absence of any prominent tendency to cleavage, the smooth crystals of this mineral are attacked much less readily than is hornblende, so that we often find them as "black gravel" in the soils formed from rocks containing it. Such soils are particularly abundant and important in the region covered by the great sheet of eruptive rocks (basalts, so-called) in the Pacific Northwest, and on the plateau of South Central India (the Deccan), and result likewise from the decomposition of the black lavas of volcanoes; thus in the Hawaiian islands, and in the Andes of Peru and Chile.

Both hornblende and augite being either free from, or deficient in potash, of course the soils formed from them are apt to lack an adequate supply of this substance for plant use. This is markedly true of hornblende schist or amphibolite rocks.

Mica, commonly known as isinglass, is so conspicuous wherever it occurs that it is more readily recognized than any other mineral. It occurs in glittering scales in soils and sands, and in rocks it sometimes forms sheets of sufficient size to supply the small panes for the doors of stoves, lamp chimneys, etc., which being flexible are not liable to break, but only gradually scale into very thin films, into which it can also be split by hand. When white, (muscovite, phlogopite) its scales are sometimes mistaken for silver by mine prospectors; when yellow, for gold; but their extreme lightness should soon remove these delusions. The composition of mica is not widely different from that of the two preceding minerals; like these it sometimes contains much iron, and is then dark bottle-green (biotite); this variety in weathering becomes bright yellow, and soon disintegrates.

This mineral is so abundant an ingredient of many rocks and soils, that one naturally looks for it to play some definite or important part in soil formation. By its ready cleavage it favors the disintegration of rocks; but it seems that owing to the extremely slow weathering of its smooth, shining cleavage surfaces, it exerts no notable effect upon the chemical composition of the soil, although, owing to its peculiar character of fine scales, it sometimes adds not immaterially to the facility of tillage in otherwise somewhat intractable soils. So far as is known at present, its presence or absence does not constitute, in itself, any definite cause or indication of the quality of any soil. It may nevertheless be said that the rock in which it usually occurs most abundantly—mica-schist, a mixture of mica and quartz—is known to form, as a rule, lands of poor quality. On the other hand, the soils derived from granites and gneisses, even when rich in mica, are usually excellent, on account of their content of feldspars, and frequently of other associated minerals.

Hydomica differs from the preceding mainly in containing a larger proportion of combined water; but it hardly decomposes more readily, and the rocks in which it mainly occurs (hydromica schists) are refractory to weathering, and in any case do not yield soils of any fertility, the mineral being associated simply with quartz.

Chlorite, essentially a silicate of alumina and iron, somewhat resembles mica but is deep green or black, in small scales. It forms part of certain rocks (chlorite schists), which greatly resemble the hornblende schists, but are usually inferior to the latter as soil-formers, containing but little of any direct value to plant life.

Talc and Serpentine, Hydrous silicates of magnesia, are extensive rock-materials in some regions, and as such require mention as soil-formers also. Serpentine usually forms blackish-green rock-masses, that although soft disintegrate very slowly in the absence of definite structure, and are attacked with some energy only when charged—as is frequently the case—with ferrous oxide. The conversion of this into ferric hydrate, so common in nature, here also serves as the point of attack on a rock otherwise very stable; causing it to crumble, even though slowly.

Talc (the true "soapstone") being usually free from iron, would be even more slow than serpentine to yield to weathering, but that its extreme softness and ready cleavage greatly facilitate its abrasion. Thus talc schist, which is usually a mixture of talc with more or less quartz, undergoes mechanical disintegration quite readily.

But the soils formed from either serpentine or talcose rocks are almost always very poor in plant food, and sometimes totally sterile. Magnesia, though an indispensable ingredient of plant food, is rarely deficient in soils and unlike lime does not influence in any sensible degree the process of soil formation. Magnesian rocks as a whole are practically found to be not specially desirable soil-formers, even in the form of magnesian limestones. They do not even, as a rule, contain as many useful accessory minerals as are commonly found in limestones. Moreover, an excess of magnesia over lime is injurious to most crops, as is shown later (chapt. 18).

The Zeolites.—Zeolites may be defined as hydro-silicates containing as bases chiefly lime and alumina, commonly together with more or less of potash and soda, more rarely magnesia and baryta. The water is easily expelled by heating, but is present in the basic form, not merely as water of crystallization. All zeolites are readily decomposed by chlorhydric and other stronger acids.

The zeolites proper are not original rock ingredients, but are formed in the course of rock decomposition by atmospheric agencies, heated water, and other processes not fully understood. They are therefore usually found in the cavities and crevices of rocks that have been subject to the influence of atmospheric or thermal waters, most frequently in eruptive rocks, particularly in the vesicular cavities characterizing what is known as amygdaloids. They are also found in the crevices of sandstones and shales percolated by water, as well as in nodules of infiltration (geodes), in which they are frequently associated with quartz. Those found in the cavities of rocks are usually well crystallized wherever room is afforded, and are readily recognized by their crystalline form; they are mostly colorless, sometimes yellow or reddish.

Exchange of bases in Zeolites.—Although zeolites rarely form a large proportion of rock masses and therefore do not enter directly into the soil minerals to any great extent, their interest in connection with soil-formation is very great, because of the continuation, within the soil, of the same processes that bring about their formation in rocks. Under the conditions existing in soils they will naturally rarely form crystals, but will appear in the pulverulent or gelatinous form, leaving the zeolitic nature of the material to be inferred from its chemical behavior. Among these characters the ready decomposability by acids has already been mentioned; another of special importance in the economy of soils is the fact that when a pulverized zeolite is subjected to the action of a solution containing either of the stronger bases usually present (potash, soda or lime), such base or bases will be partially or wholly taken up by the zeolitic powder, while corresponding amounts of the bases originally present will pass into solution.

Thus when a hydrosilicate of soda and alumina is digested with a solution of potassic chlorid or sulphate, the soda may be partially or wholly replaced by potash, while the corresponding sodium salt passes into solution. In the case of zeolites containing lime or magnesia or both, the action of potassic or sodic chlorid will be to partially replace the lime, while calcic and magnesic chlorids pass into solution, resulting in the partial or complete replacement of the lime by one or the other, or by both bases. It is important to note that, other things being equal, potash is usually absorbed in greater amounts and is held more tenaciously than soda. The process may frequently be partially or wholly reversed again, by subsequent treatment with large amounts of solutions of the displaced base or bases. Thus while a solution of potassic chlorid may be made to expel almost completely the sodium present in analcite, subsequent treatment with sodic chlorid solution will again almost completely displace the potash before taken up. The same happens when the natural mineral potash leucite, (see p. 32) of frequent occurrence in certain lavas, is pulverized and treated with a sodic solution; resulting finally in the production of a mass corresponding to natural analcite, the sodium mineral corresponding to leucite.

In other words, in any zeolitic powder the alkaline or alkaline earth bases present may be partially or wholly displaced by digestion with an excess of solution of any of these, varying according to the amount of solution employed, and the length of time and temperature of action.

This characteristic behavior of zeolites is exactly reproduced in soils. Few soils permit any saline solution to pass through them unchanged; solutions of alkaline chlorids filtered through soils almost invariably cause the passing through of calcium and magnesium chlorids, while a part of the alkaline base is retained; and as a matter of fact, we find that this absorbing power of soils for alkaline bases is more or less directly proportional to the amount of matter which may be dissolved or decomposed with elimination of silica, by means of acids.

This absorption of bases from solutions by chemical fixation will be farther discussed later on; but it should be mentioned here that both naturally and artificially, rock-masses are very commonly cemented, wholly or in part, by zeolitic material. Hydraulic concretes may be considered as sandstones or conglomerates whose grains are cemented by a zeolitic cement consisting of silica, lime and alumina, with usually some potash or soda, and of course containing the basic water; hence unaffected by the farther action of the latter substance after the time of setting has expired, which varies somewhat according to the nature of the material used. That similar cements should occur in natural sandstones is to be expected; thus we find not unfrequently that certain sandstones are materially softened, and their resistance destroyed, by treatment with even moderately dilute acid, while silica and the usual zeolite bases pass into solution. It is not often, however, that zeolitic material alone cements the sandstone; it is most frequently associated with siliceous, calcareous and sometimes even with ferruginous cementing material.[1]

CALCITE AND LIMESTONES.

Calcite or calcareous spar is one of the minerals most commonly known in the crystallized form, and is readily recognized by its perfect cleavage in three directions, producing cleavage forms with smooth, rhomb-shaped faces (rhombohedrons); these are sometimes colorless and perfectly transparent, and laid on printed paper show the letters double. But it may be whitish-opaque, and of various colors, which may also be imparted to the limestones formed from it. It is readily distinguished from quartz, which it sometimes resembles, by its cleavage, its inferior hardness, being easily scratched with a knife; and by its effervescence with acids, the latter being the crucial test when other marks are unavailable, as when it forms soft granular masses or "marls." In all cases it can be recognized by its crystalline form under the microscope, even when the substance containing it has been pulverized in a mortar. The great importance of this compound—calcic carbonate—from the agricultural point of view renders it desirable that it, as well as limestones as such, should be recognized, when seen, by every farmer.

In mass the pure mineral constitutes white marble; colored or variegated marbles are more or less impure from the presence of other minerals. Some compact limestones also are nearly pure; and as supplying only a single ingredient of plant food these would not be much better soil-formers than quartz or serpentine. But it is quite otherwise with *common* limestones; the mass of which, it is true, is formed of calc-spar, but owing to its origin, is in the great majority of cases so far commingled with other matters of various character, that limestones are

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[1] A zeolitic mass, at first gelatinous and then becoming granular-crystalline is frequently observed oozing from the lower surface of newly made concrete reservoir dams: just as we find similar oozes consolidated into natrolite crusts in the crevices of natural sandstones.

popularly reputed to form the very best soils. "A limestone country is a rich country" is a popular axiom to which there are, on the whole, but few exceptions.

Origin.—Actual observation of what is happening at the present time, as well as the examination of the rock as anciently formed, prove conclusively that with insignificant exceptions, all limestones have been formed from the framework and shells, and to some extent from the bones, of marine and fresh-water organisms, ranging in size from the extinct giants of the lizard relationship to those recognizable only by the microscope. Owing to the solubility of lime carbonate in carbonated water, the organic forms have often (in crystalline limestones) been almost completely obliterated in some portions, but in others are so preserved as to prove undeniably the similarity of origin of the whole, and that they have been formed in relatively shallow water, as they are to-day.

Impure Limestones as Soil-formers.—From what has been said regarding the composition of sea-water, it will readily be inferred that a pure deposit of any one kind cannot easily be formed in it; moreover, the matter held in mechanical suspension everywhere near the coasts must very commonly be included within the calcareous deposits formed off-shore. Hence few limestones dissolve in acids without leaving a residue of sand, clay and various other substances, usually even some organic matter not fully decomposed; sometimes less than half of the mass is really lime carbonate. It is obvious that when the solvent action of carbonated water is exerted upon such impure limestones, a loose residue of earthy matters will remain behind. It is by this process that a considerable proportion of the richest soils in the world have been formed, which have given rise to the popular maxim above quoted. They are emphatically "residual" soils; sometimes, it is true, somewhat removed, by washing-away, from their point of origin, but in many cases forming a compact soil-layer on top of the unchanged rock, into which there exists every shade of transition. Striking examples of such residual soils in place are seen in the black prairies of the southwestern United States; they are mostly rather "stiff" (clayey), and hence has arisen a local popular error, to the effect that clay or "heavy" soils are always calcareous. On the other hand, the blue-grass region of Kentucky, and most of the lands of the arid regions are prominent examples of "light" calcareous soils.

Caves, Sinkholes, Stalactites.—Perhaps the most striking exemplification of the solvent power of carbonated water is seen in the formation of limestone caves. As a matter of fact, the vast majority of all existing caves is found in limestone formations; and such formations, as will be more fully discussed hereafter, nearly always bear a luxuriant vegetation. The water filtering through the vegetable mold, in which carbonic acid is constantly being formed, becomes charged with it, and on reaching the underlying rock, dissolves to a corresponding extent the lime carbonate of which this rock wholly or chiefly consists. When penetrating crevices it soon enlarges these, to an extent proportioned to the length of time and the strength of the solvent; and thus gradually subterranean passages or caves are formed, which at first are almost always the bed of a stream, the mechanical action of which accelerates the process of enlargement, until after some time the water is perhaps drained off through some crevice to a lower level, where the same process is repeated.

Sometimes the ceiling gives way, forming the funnel-shaped "sinkholes" or "lime-sinks" so familiar in some of the Mississippi Valley States. Sometimes the lime solution on reaching the ceiling of the cave, instead of dropping down, evaporates there and eventually forms icicle-like "*stalactites*" out of the dissolved substance; while when dropping on the floor and thus growing upwards, the corresponding formation is called "*stalagmite*." These caves, subterranean rivers, sinkholes, natural bridges and tunnels, etc., mostly owe their origin to this solvent action of carbonated water on limestone formations.[1]

The same occurs on a small scale, when calcareous land is underdrained; the lime carbonate dissolved from the soil is partially deposited in the drain pipes, which it frequently obstructs. Similarly, an impure, porous deposit of calcareous tufa is frequently formed on the surface, at the foot or in rills

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[1] T. M. Reade (in his treatise on Chemical Denudation in Relation to Geological Time) calculates that 143.5 tons of lime carbonate are annually removed by solution from each square mile of land in England and Wales, and that the average amount thus removed annually from each square mile of the earth's surface is about fifty tons.

of calcareous hills. When "hard" water, being usually such as contains lime carbonate dissolved in carbonic acid, is boiled, or long exposed to the air, carbonic gas escapes and the lime salt is deposited partly on the walls of the kettle, partly forming a pellicle on the surface of the water.

Dolomite, or bitter spar, greatly resembles calcite in its aspect and properties, although containing nearly half its weight (47.6%) of magnesic, together with calcic carbonate. It is, however, nearly always whitish-opaque; its crystalline and cleavage surfaces are usually somewhat curved; and its effervescence with acids is much less lively than in the case of calcite. Like the latter it often forms pure granular rock deposits, frequently used instead of marble and limestone, and under that designation. The dolomite rocks, however, are much more subject to weathering than the non-magnesian limestones, and it is a curious fact that in contradistinction to the limestone regions proper, those having strongly magnesian limestones or dolomites as their country rock are frequently remarkably sterile. In some portions of Europe dolomite areas are sandy deserts, whose sand consists of weathered dolomite, so pure as to offer no adequate supply of mineral food to plants. In the United States, magnesian limestones underlie the "barrens" of several States and thus seem to justify their European reputation of being poor soil-formers. The exact cause of this difference is not fully understood, for at first sight it is not clear why the presence of the magnesian carbonate should interfere with the well-known beneficial effects of the lime compound. O. Loew and May[1] and others have, however, shown that a certain excess of lime over magnesia in the soil is necessary to prevent the injurious effects exerted by magnesic compounds on plant nutrition, in the absence of an adequate supply of lime. This point will be discussed more in detail farther on.

Selenite or *Gypsum,* sulfate of lime with about 14 per cent of water, though not as abundant in nature as the carbonate or limestone, is a very widely disseminated mineral and often occurs in large masses over considerable areas. These are undoubtedly in most cases the result of evaporation of sea water

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[1] Bull. No. 1, U. S. Dept. Agr. Veg. Path. and Physiol. Investig.

(see p. 26), more rarely of the transformation of limestone. In mass it frequently resembles the latter, but is readily distinguished by its softness; it does not grit between the teeth, is readily cut with a knife and does not effervesce with acids. Very commonly it occurs in crystals, which are easily split into thin plates. The crystals are very frequently found imbedded in gray or bluish, tough clays, in rosettes, or flat sheets which mostly show characteristic incurrent angles (caused by twinning), and are hence known as "swallowtail" crystals. Such sheets of selenite are popularly called "isinglass," which name however is equally applied to the mineral mica (see p. 35).

Gypsum is only exceptionally an abundant ingredient of soils; yet such soils prevail quite extensively on the upper Rio Grande, in New Mexico and adjacent portions of Chihuahua, Coahuila, and on the Staked Plains of Texas. Here whole ranges of hills are sometimes composed of gypseous sand, bear a scanty, peculiar vegetation, and are ill adapted to agricultural use. It may be said in general that few naturally gypseous soils are very productive. This is largely because of the very heavy clays which commonly accompany it, as the compound itself is not only not hostile to plant life but is in extended use as a valuable fertilizer ("land plaster") for special purposes. From causes not fully understood as yet, it particularly promotes the growth of leguminous plants, notably the clovers; and as stated in chapter 9, it also specially favors nitrification in soils. In the arid region it renders important service in the neutralization of "black alkali" or carbonate of soda in alkali soils. Being soluble in 400 parts of water, it easily penetrates downward in most soils, and in doing so effects changes in the zeolitic portions, setting free potash from silicates and thus indirectly supplying plants with this essential ingredient in a soluble form. About 200 pounds per acre is an ordinary dose.

For agricultural use the rock gypsum is ground in mills so as to be easily distributed, and dissolved by the soil water. Frequently, however, it occurs in the soft granular form (gypseous marl) requiring only light crushing; thus in the hills bordering the Great Valley of California, and in parts of New Mexico and Texas.

Iron Minerals.—In connection with calcite and dolomite, the several minerals constituting the common iron ores require mention. One of these is:

Iron Spar or siderite; carbonate of iron, corresponds in composition to calcite and dolomite and crystallizes in the same form. It sometimes occurs in large masses and is an important iron ore, brownish-white in color, and when compact resists the attack of atmospheric oxygen remarkably well. Like the carbonates of lime and magnesia, it is soluble in carbonated water, and its deposits are undoubtedly formed from such solutions. The latter are copiously formed wherever fermenting or decaying organic matter is in contact with iron-bearing materials, such as rust-colored sands or clays; and if the solution so formed can percolate without coming in contact with air, iron-spar is formed. But whenever the solution comes in contact with air, it absorbs oxygen and the ferrous carbonate is converted into ferric hydrate or rust, mineralogically known as:

Limonite or brown iron ore. This ore is frequently found deposited on the upper surface of clay layers traversing sandy strata, the clay having arrested the carbonate solution and thus given time to the air to effect the change. Sometimes such deposits form great masses in rock-caves, fissure-veins, or crevices; and like siderite, it is an important iron ore, though frequently quite impure, as in the case of *bog ore*, which is formed in ill-drained subsoils. It is also sometimes found as the residue from the weathering of rocks rich in hornblende or pyroxene, and in this, as well as in other cases, is pulverulent, constituting *yellow ochre.* It makes a rust-colored streak on biscuit porcelain or unglazed queensware. *It is the coloring material of all yellow or "red" soils and clays,* as well as of brown sandstones, which are cemented by it.

As is well known, such clays and sandstones become dark red by heating or "burning," as in the case of common brick clays; the brown or yellow ferric hydrate losing its water and becoming red ferric oxid. The latter sometimes occurs in nature in the impure, pulverulent condition, constituting "red ochre"; but more commonly and abundantly it is found in the form of

Hematite or red iron ore, which is sometimes formed in nature by limonite losing its water, but more commonly in different ways. It is but rarely found in soils and is of no special interest in that connection.

A fourth form of iron ore, quite common in the soils of some regions, is

Magnetite or magnetic iron ore, also known as lodestone. This mineral, the oxygen-compound of iron corresponding to "blacksmith's scale," also occurs in large masses and is an important and usually a very pure iron ore. It occurs very commonly disseminated through certain rocks, and in their weathering it remains unattacked and thus passes unchanged into the soils and sands, constituting the "black sand" so well known to gold miners and almost universally present in the alluvial soils of the Pacific coast. These black grains are of course attracted by the magnet and can thus be easily recognized and extracted. In soils they are simply inert, like quartz sand.

But while the ore is of little interest to the farmer, it is quite otherwise with the compound of this oxid with water, the ferroso-ferric hydrate; intermediate in composition between the white ferrous and the brown ferric hydrates. As mentioned above, the black silicate minerals, such as hornblende and pyroxene, are bottle-green when seen in thin sections. Nearly the same color, with modifications running toward blue and bright green, is often seen in natural clays and rocks, and is almost always caused by the ferroso-ferric hydrate. Such materials always become red or reddish when heated by the formation of red ferric oxid; while when exposed to damp air, they assume the rust color of ferric hydrate.

Reduction of ferric hydrate in ill-drained soils.—When such oxidized, rust-colored clays or soils are exposed to the action of fermenting organic matter, the first effect observed is the change of color from rusty to bluish or greenish, by the reduction of the ferric to ferroso-ferric hydrate. Afterward, if the action is continued, the solution of ferrous carbonate (see above) may be formed, and the greenish or bluish color may disappear.

The importance of this reaction to farming practice lies in the fact that the blue or green tint, wherever it occurs, indicates a lack of æration, usually by the stagnation of water, in consequence of imperfect drainage. Such a condition, always injurious to plants, becomes doubly so when it is associated with the formation of a metallic solution, such as ferrous carbonate, and promptly results in the languishing or death of plants in consequence of the poisoning of their roots. In the presence of sulfates such as gypsum, the formation of iron pyrites (ferric bisulfid) and sulfuretted hydrogen, is likely to take place. Moreover, under the same conditions the phosphoric acid of the soil may be concentrated into ferrous or ferric phosphate, which pass into deposits of bog ore in the subsoil.

CHAPTER IV.

THE VARIOUS ROCKS AS SOIL-FORMERS.

Rock-weathering in arid and humid Climates.—From what has been said in the preceding chapters of the physical and chemical agencies concerned in rock-weathering, it is obvious that climatic differences may materially influence the character of the soils formed from one and the same kind of rock. Since kaolinization is also a process of hydration, the presence of water must greatly influence its intensity, and especially the subsequent formation of colloidal clay; so that rocks forming clay soils in the region of summer rains may in the arid regions form merely pulverulent soil materials. Many striking examples of these differences may be observed, *e. g.*, in comparing the outcome of the weathering of granitic rocks in the southern Alleghenies with that of the same rocks in the Rocky Mountains and westward, especially in California and Arizona. The sharpness of the ridges of the Sierra Madre, and the roughness of the hard granitic surfaces, contrasts sharply with the rounded ranges formed by the " rotten " granites of the Atlantic slope, where sound, unaltered rock can sometimes not be found at a less depth than forty feet; while at the foot of the Sierra Madre ridges, thick beds of sharp, fresh granitic sand, too open and pervious to serve as soils, cover the upper slopes and the " washes " of the streams, causing the latter to sink out of sight. A general discussion of the kinds of soils formed from the various rocks must, therefore, take these differences into due consideration.

GENERAL CLASSIFICATION OF ROCKS.

Rocks may be broadly classified into three categories, viz:

1. *Sedimentary* rocks, formed by deposition in water and hence more or less distinctly stratified.

2. *Metamorphic* rocks, formed from rocks originally sedimentary, by subterranean heat in presence of water. Usually

crystalline, that is, composed of more or less distinct (large or minute) crystals of one or several of the minerals mentioned above.

3. *Eruptive* rocks, ejected in the molten state from volcanoes or fissures; crystalline or not, according to slow or rapid cooling.

Sedimentary Rocks.—Sedimentary rocks are forming to-day by deposition from either sea or fresh water, precisely as they were in the most remote geological times; the oldest clearly sedimentary rocks being sometimes undistinguishable in their nature and composition from the very latest immediately preceding our present time. They may for the purposes of the present work be simply classified as follows:

1. *Limestones,* formed in comparatively shallow seas, or fresh water basins, from the calcareous shells or skeletons of various organisms.

2. *Sandstones,* and conglomerates (sometimes called pudding-stones) formed from the debris of pre-existing rocks disintegrated by the agencies described above, (chap. 1–2), re-cemented by means of solutions of one or several substances, such as silex, carbonate of lime, ferric hydrate and others. Loose sands and gravels are the initial stages of such rock formation as well as the results of their disintegration.

3. *Clays, Claystones and Clay shales,* consisting of clay substance with more or less sand, and soft or hard according to the nature of the waters or solutions that may have acted upon them, with or without the aid of heat. These rocks can only be formed in comparatively quiet or "back" waters, since clay would not ordinarily be deposited in moving water.

Metamorphic Rocks.—The effects of subterranean heat or metamorphism upon the sedimentary rocks may be roughly stated as follows:

Limestones are transformed into marbles of various degrees of purity, according to the nature of the original rocks.

Sandstones when cemented by silex are transformed into quartzite, of greater or less purity according to the nature of the "sand" entering into its composition. When cemented by materials other than quartz, these also will be segregated in the form of various minerals in the body of the rock.

The *clay rocks* form the most varied products under the influence of (aqueo-igneous) metamorphism; granites, gneiss, syenite and hornblendic schist are among the most common. The great variations in the composition of clayey materials account for the correspondingly great variations in the nature of the resultant metamorphic rocks.

Igneous or Eruptive Rocks.—These are usually divided into two groups; the one characterized by a large proportion of free quartz (silicic acid), and hence designated as *acidic,* and usually of a light tint; the other the *basic,* containing little or no free quartz, and commonly of a dark tint caused by the presence of a large amount of iron (contained in pyroxene, more rarely in hornblende).

Of the latter class are the dark "basaltic" rocks constituting the mass of the enormous eruptive sheet of the Pacific Northwest, covering the greater part of Washington, Oregon and northeastern California. The lavas of the Hawaiian islands are of the same class and even more basic; while the eruptives of Nevada, middle and southern California, and eastward to the Rocky Mountains, are mostly of the light-colored, acidic type. The same is largely true of the rocks of the Andes of Central and South America, the gray "Andesites," also represented in the Caucasus.

As one and the same eruptive material may, according to the greater or less rapidity of cooling, appear as a glassy mass (obsidian, pumice, volcanic ash, tuff, etc.,) or as a crystalline rock resembling coarse granite in structure, it is not easy to identify them in all their various forms. This can frequently be done only by ascertaining their component minerals by the microscope, or by chemical analysis. The same is sometimes true of metamorphic rocks; and as in the latter, the several feldspars and quartz, with pyroxene instead of hornblende, constitute the predominant soil-forming minerals. More rarely, garnet, chrysolite, leucite and other silicates require consideration.

Generalities regarding the Soils derived from various Rocks.

It is hardly necessary to insist that as in the case of the rocks composed of single minerals, already referred to above, the predominant mineral or minerals of compound rocks determine the facility of weathering, as well as the quality of the soil resulting therefrom. Since rocks are named essentially in accordance with the *kinds* of minerals that constitute their regular mass, the *proportion* in which the several constituents stand to each other may vary greatly. Thus a *granite* may consist, over considerable areas, mainly of a mixture of potash feldspar and quartz; in others, mainly of quartz and mica with little feldspar. Very frequently, hornblende replaces mica partially or wholly. The latter will weather much more slowly than feldspar or hornblende, and will produce an inferior soil when decomposed. Allowing for such variations, a fairly approximate general estimate of the quality and peculiarities of soils from crystalline rocks may nevertheless be made. To some extent such estimates must make allowance not only for the chief ingredients, but also for those which are called "accessory" or characteristic, and which while not present in large amount, may nevertheless exert a considerable influence upon the quality of the soil.

Soils from granitic and crystalline rocks.—In the case of the (potash-feldspar) granite soils it is generally admissible to expect that they will be fairly supplied with phosphoric acid, because in the great majority of cases, minute crystals of apatite (phosphate of lime) are more or less abundantly scattered through it. From the potash feldspar present, granite soils may always be relied on for a good supply of potash for plant use; on the other hand, unless hornblende be present, they are pretty certain to be deficient in lime, since neither lime, feldspar nor calcite are probable accessory ingredients of this rock.

Granite is exceedingly apt to weather by mechanical disintegration far in advance of its chemical decomposition. It is therefore common to find in sedentary soils overlying granite, a gradual increase of grains of its component crystalline minerals as we descend in the subsoil; until finally the latter grades off into rock almost unchanged save in lacking coherence. This is seen strikingly in the southern Appalachians, as well as in the Sierra Nevada and Sierra Madre of California; at Cintra in Portugal, at Heidelberg in Germany, and elsewhere.

But of the rocks that resemble granite and are popularly so called, a good many are not "true to name" and therefore form soils differing materially from the type just mentioned.

Thus the so-called granite areas of the Sierra Nevada of California are largely occupied by a rock containing, besides quartz, chiefly soda-lime feldspar and some hornblende, and scarcely any mica. It is more properly a diorite (grano-diorite); the soils formed from it are rather poor in potash, not strongly calcareous, and quite poor in phosphoric acid. On account of the small proportion of hornblende (unusual in diorites), these soils are light-colored (not "red"), and bear a growth of small pine instead of the usual oak growth of the lower Sierra slopes.

What is said of granite soils is also generally true of those formed from

Gneiss, which is composed of the same minerals as granite, but has a slaty cleavage and on that account when upturned on edge, weathers rather more rapidly than most granites. Owing to the frequent occurrence of lenticular masses of quartz in gneiss, its soils are more commonly of a siliceous nature than are those of the true granite regions, and not as "strong" as the latter. This is the more true since gneiss often passes gradually into *mica schist*, which, being a mixture of quartz and mica only, not only weathers very slowly but also supplies but little of any importance to plants, to the soils formed from it. Such soils would mostly be absolutely barren but for the frequent occurrence in the rock, of accessory minerals that yield some substance to the soil. Yet it remains true that inasmuch as gneiss and mica-schists are among the rocks in which mineral veins most commonly occur, the proverbial barrenness of mining districts is very frequently traceable to these rocks. The same may be said of some of the related rocks, such as gabbro, minette and others.

Normal *diorite* consists of hornblende and soda-feldspar, with more or less quartz.

The soils derived from certain diorites of the Sierra Nevada of California have just been referred to. But these granite-like diorites are on the whole exceptional; it should be added that the (diabasic) "greenstones" of the Eastern United States and of the Old World, which are usually much finergrained, do not form the mass of fine, angular debris constituting the subsoil in the Sierra Nevada, but weather into rounded masses and fine-grained soils possessing, on the whole, a fair fertility, though liable to contain an excessive proportion of silex in various forms.

Of the *eruptive rocks* as a class it is often said that they form very productive soils; yet, as these rocks differ widely from each other in composition, this statement must be taken with a great deal of allowance. Very many of them decompose with extreme slowness on account of their glassy nature; this is particularly true of obsidian, pumice stone, and the " volcanic ash " derived from its pulverization, and which is found unchanged, in sharp scales, among the decayed minerals of other rocks in complex soils. Other volcanic ash, however, being formed by the pulverization of crystalline or of basic lavas, weathers rather readily, as already stated; so that certain plants take possession in the course of a few years. The general classification into basic and acidic rocks, given above, is of importance in connection with soil formation from eruptive masses; for the basic rocks are much more easily attacked by the atmospheric agencies than the acidic class.

A broad distinction must, however, be made between the basic rocks of the basaltic class, which contain black pyroxene as a prominent ingredient, and those which, like many trachytes, are rich in feldspathic minerals. The latter are naturally rich in alkalies (potash and soda) which they impart to the corresponding light-colored soils; while the black basaltic rocks and lavas weather into "red" soils, sometimes containing extraordinary amounts of iron (ferric hydrate) and (from the lime-feldspars they contain) a fair supply of lime, but oftentimes very little potash. Experience seems to prove that the red basalt soils are mostly rather rich in phosphoric acid; this is especially true of the country covered by the great eruptive sheet of the Pacific Northwest, in the rocks of which the microscope readily detects the presence of numerous needles of apatite (lime phosphate). The same is true of the highly iron-bearing soils from the black basaltic lavas of the Hawaiian islands, even though they have been leached of all but traces of lime and potash. All these soils are physically "light" and easily workable, since the rocks in question contain but little alumina from which to form clay; they are sometimes extremely rich in iron, even to the extent of being capable of serving as iron ores.

The soils derived from *trachytes* and trachytic lavas are generally light-colored and light in texture; the latter from the presence of a large proportion of volcanic glass, together with undecomposed crystalline minerals. These are usually rich in potash, but poor in lime and phosphates. The high quality of the wines of the lower Rhine has been ascribed to these soils, which however vary greatly within the areal limits of the production of the high-grade wines, not only from gray trachytes to dark colored, highly augitic basalt, but also to acidic quartz porphyries or rhyolites, and clay-slates.

The rhyolites on the whole yield the poorest soils among the eruptive rocks; they are slow to weather at best, and the soils produced are poor and unsubstantial, largely from the predominance of quartz and undecomposable, glassy material; of which the phonolites are the extreme type, resisting the influence of the atmospheric agencies just as would so much artificial glass. Soils consisting largely of volcanic glass may be found covering considerable areas in the Sierra Nevada of California. Such " volcanic ash " soils are usually very unthrifty, and bear a growth of small pines.

Soils from sedimentary rocks.—Limestones, when pure and hard, are very slow to disintegrate, and are also very slowly attacked by carbonated water (see chap. 3, page 41). Soft impure and vesicular limestones are, however, very rapidly attacked, especially when underlying a surface clothed with the luxuriant vegetation that usually flourishes on soils rich in lime. The popular adage that " a limestone country is a rich country," is of almost universal application and stamps lime, from the purely practical standpoint, as one of the most important soil ingredients.

Residual Limestone Soils.—Striking examples of the formation of large, fertile soil areas by the leaching out of limestones are found in the States of Alabama, Mississippi, Louisiana and Texas, where the fertile black prairies have been largely thus formed. The " blue-grass " country of Central Kentucky is another case in point.

The following table shows a representative example of the relative composition of the (cretaceous) " Rotten Limestone " of Mississippi, and the " residual " soil-stratum derived from it. The average thickness of the layer of residual clay above the limestone is about eight feet, but ranges from seven to ten; the upper layers of the limestone are somewhat softened, but the rock is always fresh at twelve feet, from which depth the sample analyzed was taken, in a cistern adjoining the field from which the soil and subsoil were procured. The black soil varies in depth from 8 to 15 inches; then there is a change to a brownish subsoil, reaching down to about two feet, and in drying cleaving into prismatic fragments. The black soil has here in the highest degree the peculiarity of crumbling in drying from its water-soaked condition, so that it may be plowed when wet without injury, although in the roads it works up into the toughest kind of mud. The prairie is sparsely timbered with compact, fair-sized black-jack oak, accompanied originally by red cedar.

The limestone derives its popular name of "rotten" from its being usually soft enough to be cut with a knife or hatchet, and is therefore somewhat used for building, and for burning lime.

COMPOSITION OF LIMESTONE, AND RESIDUAL SOIL AND SUB-SOIL, FROM BLACK PRAIRIE, MONROE CO., MISSISSIPPI.

	"ROTTEN LIMESTONE."	SUBSOIL (YELLOW).	SOIL (BLACK).
FINE EARTH. Chemical analysis of fine earth.	Depth..12 ft.	2–3 ft.	15 ins.
Insoluble matter	10.90	71.54	78.29
Soluble silica			
Potash (K_2O)	.25	.54	.33
Soda (Na_2O)	.32	23	.08
Lime (CaO)	45.79	1.08	1.37
Magnesia (MgO)	.88	.77	.36
Br. Ox., of Manganese (Mn_3O_4)	....	.05	.14
Peroxide of Iron (FeO)	1.42	5.42	14.22
Alumina (Al_2O_3)	1.96	13.15	
Phosphoric Acid (P_2O_5)	....	.05	.10
Sulfuric Acid (SO_3)	....	.04	.03
Carbonic Acid (CO_2)	35.73		
Water and Organic matter	2.84	6.99	5.75
Total	100.09	99.86	100.67
Humus	....	....	1.93
" Ash	....	....	4.38
Hygroscopic moisture	....	10.35	12.82
absorbed at °C	....	19°	19°

It appears from the above table that in the change from the original limestone to the soil mass as found at three feet depth, 81.5% of the lime carbonate has been eliminated by leaching, leaving behind somewhat less than one fifth of the original mass. Taking the average depth of the soil mass at 8 feet, this thickness of material has required about 45 feet of the rotten limestone. Considering that notwithstanding the tenacity of the clay soil, some of it must in the course of time have been washed away, we may safely assume that the original rock surface was from 50 to 60 feet higher than at present.

Sandstone Soils.—The indefiniteness of the nature of "sandstones" as such renders generalizations in regard to the soils formed from them rather difficult, save as to their physical qualities, which in the nature of the case are always "light." In the Old World and in the humid region generally, sandstone and sandy soils are usually spoken of as being poor, because there the sand almost always consists of quartz grains only, and hence the fine portions alone can be looked to for plant nutrition. Consequently, the more sand is seen in a soil, the poorer it is usually presumed to be. But this presumption would be wholly erroneous in the arid regions. (See chapt. 6, p. 86).

Clearly, the nature of the soils produced by the weathering of sandstones depends upon two points: first, the nature of the cement binding the sand grains, and second the character of the latter themselves.

Varieties of Sandstones.—As has been stated above, the cements may be roughly classified into five kinds, and their intermixtures, to wit: *quartzose* or siliceous,, *calcareous, ferruginous, aluminous or clayey,* and *zeolitic.* As regards the first, it is obvious that siliceous sandstones will disintegrate with great difficulty, since neither the cement nor the grains are susceptible of material change by weathering. Such sandstones frequently pass insensibly into quartz rock, and the light, unsubstantial soils they produce are of the poorest, containing often mere traces of the plant-food ingredients. This of course, is true, not only of the soils formed by the actual weathering of sandstones, but equally of those consisting of quartz-sand deposited by water or drifted by winds.

Of this character are the pine-forest soils of the coast region of the Gulf of Mexico, particularly the "Sand hammocks" of the immediate Gulf border, from Mississippi Sound to Charlotte Harbor, Florida; the sandy lands of the Grand Traverse region of Michigan, and many other minor areas in the United States, usually characterized by a pine growth, often more or less stunted, according to the nature of the sand grains.

Calcareous sandstones usually form a very much better class of soils, partly for the intrinsic reason given above as regards limestones as soil-formers. The calcareous cement is very rarely pure calcite; in most cases it is very impure, as, most commonly, is also the "sand" itself. This is explained from the fact that such rocks (mostly soft and often quite unconsolidated) are, like limestones themselves, the result of deposition in shallow seas or lakes, receiving deposits from the land drainage, and enriched by the animal and vegetable life of such waters. Not uncommonly they contain, disseminated through them, grains of the mineral glauconite (a hydrous silicate of iron and potash), which readily supplies available potash; while the remnants of animals and plants furnish more or less of available phosphates. Thus the general presumption regarding calcareous sandstones is that the derived soils are of good quality, frequently of the very best. The same, however, does not appear to be true of sandstones cemented by dolomite; the soils derived from magnesian sandstones are in many cases noted for their unproductiveness. (See chapt. 3, p. 42).

Ferruginous Sandstones manifestly derive no important soil ingredients from their cement when the latter is measurably pure ferric hydrate; and when in addition the sand itself is purely siliceous, the soils resulting from the disintegration of the rocks are very poor.

Such are, e.g., the soils derived from the ferruginous sandstones of the Lafayette formation in a part of northern Mississippi and adjacent portions of Tennessee and Alabama, characterized by small scrubby oak or dwarfed pine. On the whole, however, such purely ferruginous quartz sandstones are exceptional, and should not detract from the favorable inferences usually to be drawn from the iron-rust tint of soils (see chapter. 15

Sandstones with purely *zeolitic* cement are on the whole not of frequent occurrence, the zeolites forming, more commonly, the hard portion of a clay-sandstone cement, which disintegrates by their weathering-out.

In regions where the tufaceous rocks of eruptives prevail, we not uncommonly find the "volcanic ash" solidly cemented by a zeolitic mass, which is then usually apparent in cavities or crevices in the form of crusts or crystals. Such tuffs are commonly rich in alkalies and lime, but mostly poor in phosphates, and in disintegration form soils of a corresponding nature. They are largely represented in the valleys off Puget Sound, as well as in portions of central Montana, and northward.

Clay-Sandstones (argillaceous sandstones) when soft, as is mostly the case, form as a rule desirable loam soils, of a generalized composition, difficult to predict. It is here that the composition of the sand grains themselves most frequently comes into play in modifying the soil quality. From clay-sandstones to claystones of various degrees of sandiness there is, of course, every grade of transition, the soils ranging correspondingly in the scale of lightness or clayeyness. As a general rule, the potash contents of such soils are sensibly proportioned to the clayey ingredient, at least in the humid regions.

Claystones (i. e., clays hardened by some one or more of the cements mentioned in connection with sandstones), will in the nature of the case, when disintegrated from the condition in which they lie in the geological formations, make correspondingly clayey, heavy soils, which as experience shows are usually rich in the ingredients of plant food, but frequently too heavy and intractable in tillage to be readily utilized.

There are, of course, exceptions; such as soils formed from pipe-clays, in which little if any mineral plant-food remains, and which are best used for other purposes than agriculture, unless under special conditions it may be worth while to reclaim them by fertilization.

Natural Clays.—Clays occur in nature in a great variety of modifications that have received designations known in common life. Such are porcelain clay, pipe-clay, fire-clay, potters' clay, brick-clay, and many others of more or less local use only. As these materials practically concern the farmer in very many cases, they may properly find a brief discussion here.

The variety-names enumerated above in the order of the actual contents of the materials in true clay substance (" colloidal clay "), are partly based upon that fact, partly upon the degree of plasticity attained by that substance, and essentially upon the nature and amount of foreign admixtures associated with it. Thus, porcelain clay is chalky kaolinite, sometimes associated with enough of pure white plastic clay to render it workable in the potter's lathe, but more commonly requiring to be molded in porous molds; it is very refractory to heat. Pipe-clay is also white, but more plastic and usually less refactory. Fire-clay is a refractory pipe-clay commingled with some coarse infusible material, such as quartz sand (or the same clay burnt and crushed), in order to prevent excessive contraction and change of shape in drying and burning. Potters' clay is a much less pure, and from that cause more fusible clay, which when burnt forms at a moderate heat a semi-fused, more or less hard mass, such as crockery and pottery ware. Brick-clay is a still more impure clay, or loam, containing considerable sand and usually iron oxid, and largely falls already within the limits of tillable soils or subsoils, rendered fusible by the presence of relatively considerable amounts of iron, magnesia and lime.

Iron colors natural clays either red, yellow, green or blue; the latter two colors turning to yellow or red on exposure to the air, and to red on burning. Black color is usually due to carbon, such clays often turning white on heating.

Clays containing much lime are usually of a gray or whitish tint, and like the soft crumbly limestones are often called marls, and are used as such for land improvement. But it should be understood that the colors of clays, mostly derived from some iron compound, have little to do with their uses in the arts, except that no deeply colored clay (black excepted) is refractory in the fire.

"Colloidal" Clay.[1]

In connection with soils, clay may be defined, in the most general terms, as being the substance which imparts plasticity and adhesiveness to soils when wetted and kneaded, and which, when heated to redness, loses this property completely and permanently, becoming hard and coherent in proportion to the degree of heat to which it is exposed.

In common life, however, the name is applied to the whole of any naturally occurring earth which on wetting and kneading assumes a reasonable degree of plasticity and adhesiveness. When the latter property becomes nearly or quite insensible, the earth is designated as a "loam," more or less "clayey" according to the amount of the pure, plastic and adhesive material associated with the mineral powders and sand that form the bulk of most soils.

Chemically, the pure clay substance[2] probably consists (as has been stated above) of silica and alumina in the proportion of nearly 46 to 40, the rest (14%) being water of hydration, which is lost on burning the clayey material. But while it is true that such is the composition of the plastic substance of clays, plasticity and adhesiveness are by no means invariable properties of this compound. In its purest state, as kaolinite, it is readily mistaken for chalk, (and is sometimes used as such), being powdery to the touch and entirely devoid of plasticity[3] when wetted and kneaded. The microscope shows this

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[1] This term was first employed by Th. Schloesing, in communications to the French Academy of Sciences, and reported in the Comptes Rendus of that body; first in 1870. Unaware of Schloesing's work, the writer began a full investigation of the subject of mechanical soil analysis in 1871, and published the results in 1873 (Am. Jour. Sci., Oct. 1873). Up to that time the limited resources of the library of the University of Mississippi had not given him an opportunity to see Schloesing's publication. The two independent investigations, though conducted on somewhat different lines, gave of course practically the same results, and complement each other.

[2] There is still some discussion as to the chemical identity of colloidal clay with Kaolinite; but the objections are not convincing.

[3] It has of late been attempted to extend the meaning of this word to the behavior of all powders when wetted with water. But the adhesive plasticity of clay stands almost alone, in that (aside from contraction) it preserves in drying the form into which it may have been molded while wet, even when struck, whereas other powdery substances similarly treated at once collapse back into the original powder. The exclusive use of clay in modeling offers the typical example of plasticity as generally understood. The addition of any powdery substance, however fine, diminishes the plasticity of clay.

chalky kaolinite to consist of minute, mostly rounded, originally six-sided, thin plates, which when pure resemble to the touch powdered talc (soapstone) or even black-lead, rather than any clay known to common life. But being exceedingly soft, the kaolinite substance is easily ground or triturated into an extremely fine powder; and Johnson and Blake[1] succeeded in producing sensible plasticity and adhesiveness by long-continued trituration of kaolinite with water in a mortar. A similar process, but continued much longer by the mechanical agencies concerned in soil-formation (see chapt. 1), is unquestionably the chief factor concerned in the formation of natural plastic clays; but whether this is the *only* process by which the powdery kaolinite may be transformed into plastic clay, is a question not definitely settled. It is at least possible that repeated freezing and thawing, as well as the action of hot water, may take a part in the transformation, beyond that by which they destroy the crumbly (flocculated) structure of soils and clays, and render them plastic; as is done in the maturing of clays by potters.

Causes of Plasticity.—In any case the property of plasticity and adhesiveness is restricted to the particles so fine that they fail to settle, in the course of 24 hours, through a column of pure water eight inches (200 m) high, while some are so extremely minute that they will not settle for many months, and even for several years.[2] Such turbid "clay water" may

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[1] American Journal of Science, 2d Ser., Vol. 43, p. 357.

[2] Williams (Forsch. Agr. Phys. Vol. 18, p. 225 ff.) claims that the diameter of the minutest clay particles is one-thousandth of a millimeter, their form being that of scales showing continual (Brownian) motion in water. He maintains that the plasticity of clay is due to this minute size, and this view has gained wide acceptance in late works on the subject. But this assumption cannot be maintained in the face of the fact that nothing like the adhesive plasticity of clay can be attained even by the finest powders of other substances, least of all by those having the closest mineralogical resemblance to kaolinite, such as graphite and talc. Above all, the most persistent trituration with water utterly fails to restore plasticity to clay once baked so as to expel its water of hydration, although the fineness of the particles is thereby not only not diminished, but actually increased, by contraction in heating. No powders however fine can replace the functions of clay in soils, *viz.* the maintenance of floccules, and tilth dependent thereupon; and they distinctly impair the plasticity of clay. The fine "slickens" of quartz mills merely render soils containing them more close and impervious, and more difficult to flocculate. Even gelatinous masses like hydrated ferric and aluminic oxids fail to replace clay in its adhesive functions.

sometimes be found existing in nature, in moist, secluded places, for weeks after the subsidence of the overflows of rivers whose water is exceptionally free from dissolved mineral matter.

Separation of Colloidal Clay.—This property of the plastic clay substance, of diffusing in pure water, furnishes the means of separating from it the coarser, sandy and silty portions of soils and natural clays, and observing its characteristic properties, so far as the almost unavoidable admixture of some other substances, presently to be considered, permits.

In natural soils the clay particles usually incrust the powdery ingredients, cementing them together; or themselves form complex aggregates (floccules) of large numbers of individual particles. These may be loosened from their adhesion or cohesion either by prolonged, gentle kneading of the wet clay, or by more or less prolonged digestion (soaking) in hot water, or more expeditiously, by lively boiling with water. The boiling should not, however, be prolonged beyond the time actually required for disintegration, since (as Osborne[1] has shown) long-protracted boiling tends to render the clay permanently less diffusible.

From the turbid clay-water the diffused clay may be obtained either by evaporating the water (which as the bulk is very large, is usually inconvenient), or, more conveniently, by throwing it down from its suspension by the action of certain substances which possess the property of curdling (coagulating) the clay substance into flocculent masses that settle quickly. Of all known substances, lime, in the form of lime-water, acts most energetically in producing this change; but other solutions of lime, as well as most salts and mineral acids, produce the same effects when used in sufficient quantity. Common salt is among the most convenient, because it can most readily be leached out of the clay precipitate thus thrown down. This when white, resembles boiled starch, but being usually colored by iron might be easily mistaken for the mixed precipitate of ferric hydrate and alumina so commonly obtained by chemists in soil analysis. When separated from the water and dried, the jelly-like substance ("colloidal clay") shrinks as extravagantly as would so much boiled starch, into hard, shiny crusts or flakes, which when struck in mass are sometimes even resonant, and bear more resemblance to glue than to the clay of everyday life. Like glue, too, but much more quickly and tenaciously, the dried colloidal

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[1] Rep. Conn. Agr. Expt. Stn., 1886, 1887.

clay adheres to the tongue, so as to render the separation painful; when wetted it quickly bulges with great energy, and in a short time resumes its former jelly-like condition. When moistened with less water it assumes a highly plastic and adhesive condition, so that it is difficult to handle and almost as sure to soil the operator's hands as so much pitch.

Effects of Alkali Carbonates upon Clay.—The carbonate of potash and soda, when in very dilute solution (.01 to .05%) exert upon diffused clay an effect the reverse of the acids and neutral salts. They destroy the flocculent aggregates formed by precipitation with these, or naturally existing in the soil, and tend to puddle the clay so as to render it impervious to water. It is thus that in the alkali lands of the arid regions we often find the soil or subsoil consolidated into a very refractory "hardpan," difficult to break even with a sledge hammer and impossible to reduce to tilth until the alkali carbonate is destroyed by means of a lime salt, such as gypsum. (See chapt. 23). Ammonia water also helps to cause the diffusion of clay in water, but its effect of course disappears upon drying. It is probable that this property of sodic carbonate can be utilized in rendering earth dams firmer and more secure against the penetration of water.

CHAPTER V.

THE MINOR MINERAL INGREDIMENTS OF SOILS; MINERAL FERTILIZERS; MINÈRALS INJURIOUS TO AGRICULTURE.

(A.) MINERALS USED AS FERTILIZERS.

OF minerals important in soil-formation, not usually present in large amounts in rocks, but extensively used in fertilization, the following require mention:

Apatite; phosphate of lime containing more or less of the chlorids and fluorids of the same metal; the mineral from which the phosphoric acid of the soil is mostly derived. In the crystallized condition when perfectly pure it is colorless; but it is mostly of a greenish tint (hence "asparagus stone"). The pure crystalline mineral rarely occurs in large masses (as in Canada); but small to minute crystals are found widely disseminated in many rocks (granites, "basalts" of the Pacific Northwest), thus passing into the soils formed from these rocks. These crystals are readily recognized, being regular six-sided prisms with a flat or obtusely pyramidal termination (distinction from quartz), and do not effervesce with acids (distinction from calcite). By far the largest deposits of this mineral occur in connection with carbonate of lime, in the rock materials known as *phosphorites.* Lime phosphate being, like the carbonate, soluble in carbonated water, the two naturally frequently pass into solution, and are subsequently deposited together. Most limestones contain a small proportion of lime phosphate, being, as already stated, formed from the shells and the framework of animal organisms usually containing also phosphates. But the content of phosphates in limestones is not readily apparent to the eye, and the richest deposits, save such as contain animal bones, have long passed unsuspected as to their being anything else but limestone. Systematic search has now revealed the presence of phosphate rock in numerous localities, chiefly where limestone formations occur. In the United States, in South Carolina, Florida, Alabama, Tennessee, Kentucky, Nevada; in South America, on Curaçoa island, Venezuela; in the Antilles on Sombrero, St. Martins and Navassa islands. In Africa, in Algiers and Tunisia; in Europe, in Spain (Estremadura, one of the first deposits known), France, Belgium and the adjacent parts of Germany; in Bohemia and Galicia in Austria; and very extendedly in European Russia. Many islands of Oceanica supply phosphorites derived from the decomposition of bird guano by the coral limestone.

Unfortunately the percentage of phosphate in a large proportion of these materials is not sufficiently high to make their conversion into water-soluble superphosphate economically possible at the present time; since all the calcic carbonate present must also be converted into comparatively worthless sulphate (gypsum) by the use of sulfuric acid; and as yet no practicable method for avoiding this difficulty has been found.

" *Thomas Slag.*"—Probably the nearest approach to such a method is indicated by the fact that a compound containing four instead of three molecules of lime to one of P_2O_5, such as is contained in the "Thomas slag" of the basic process of steel manufacture, is nearly or in some cases ("sour" soils) *quite* as effective for the nutrition of plants as the water-soluble superphosphate. This discovery has rendered available for agricultural use the phosphoric acid contained in the enormous deposits of limonite iron ore known as bog ore, which contains a large proportion of ferric phosphate and from that cause has until lately been excluded from the manufacture of wrought iron and steel. It is reasonable to hope that by some analogous process the low-grade phosphorites, such as those of Nevada and the plains of Russia, will also in the course of time become available for agricultural use. Extremely fine grinding and washing (producing "floats") has been resorted to for the purpose of rendering the raw phosphorites effective in fertilization. But while this is successful on some soils, on others the "floats" remain almost inert; so that this method has found only limited acceptance.

Animal bones, which consist of from 24 to 30% of animal substance and 70 to 76% of "bone earth," (or when fossil are free from the former), are largely used for the manufacture of superphosphate. The bone-earth consists in the main of tri-calcic phosphate with from one to two per cent. of calcium fluorid (much as in natural apatite), a small amount of magnesic phosphate, and about 4 to 6% of calcic carbonate. Bone meal can therefore supply to plants both phosphoric acid and nitrogen, and the presence of the latter has been largely the cause of a material overestimate of its efficacy as a fertilizer in the past. Wagner's and Maerker's experiments have shown that at least in sandy soils poor in humus, it cannot be considered an adequate source of phosphoric acid for annual crops, and that in these soils its immediate effects are almost wholly due to its nitrogen-content. The slow availability of the phosphoric acid renders it unprofitable as a source of the latter, outside of the heavier lands with abundance of humus; in "sour" lands (notably on meadows) bone meal produces its best results. In soils naturally calcareous, or in such as have received heavy dressings of lime either as carbonate or in the caustic condition, the manurial effects of bone meal are seriously diminished. Nagaoka (Bull. Coll. Agr. Tokyo, Vol. 6, No. 3) shows that the crop of rice fertilized with bone meal was reduced to less than half when limed, and that the phosphoric acid taken up by the crop was reduced to one-sixth. In any case it is most important that bone meal should be as finely ground as possible, as in the case of the phosphorites; and this can best be done when it has first been freed from fats by boiling with water, and then steamed under pressure. It can then also be most readily converted into superphosphate.

The phosphate minerals and the fertilizers manufactured therefrom are of primary importance to agriculture. The phosphoric-acid content of soils is mostly very small, and only a fraction of it is usually in an immediately available form. Hence for permanent productiveness, and especially for intensive farming or gardening, a cheap supply of phosphate fertilizers is of first importance in all soils and climates.

Other phosphate minerals occur frequently, but as a rule only in small amounts, in connection with the ores of most metals. The only ones of these of interest to agriculture are

Vivianite and *Dufrenite,* the phosphates respectively of the protoxid and peroxid of iron. The former occurs in mineral deposits as small blue crystals, or more frequently as blue earthy masses or streaks, in the substrata of rich alluvial ground (Louisiana, California). Dufrenite sometimes results directly from the oxidation of the protoxid mineral, which then turns greenish and finally brown. Unfortunately these minerals, rich as they are in phosphoric acid, cannot readily be utilized as sources of phosphate fertilizers, because of the difficulty of getting rid of the iron. Their occurrence usually suggests the presence of abundance of phosphoric acid in the soil. But that which is actually combined with the iron oxids is practically unavailable to plants; especially so in the case of the peroxid compound, the formation of which is a common source of loss of phosphoric acid when soils rich in iron are submerged for any length of time; a point which is discussed below (chapt. 13).

Among the iron phosphate minerals, may also be mentioned "bog ore," which results from the reductive maceration of swamped ferruginous soils, and accumulates in the subsoils and in the bottom of swamps or moors, forming "moorbedpan"; a dark brown, rather soft mass, which is sometimes used as an iron ore, especially since the invention of the "basic process" of iron smelting, one of the products of which is the phosphate or Thomas slag. (See above).

Nitrate of Soda or Chile saltpeter.—This mineral being (like all nitrates) easily soluble in water, can only occur in regions nearly or quite destitute of rainfall. Such is the case in the Plateau of Tarapacà in Northern Chile, where it occurs in large quantities; it is likewise found, but to much smaller extent, in Nevada, southern California, Egypt and India. By far its most extended occurrence is that in Chile, where, together with common salt, it fills cavities and crevices in a gravelly clay that forms the surface of a plateau from three to six thousand feet above the sea. It is never pure, but always mingled with a large proportion (up to 50% and over) of common salt; also some Glauber's salt (sulfate of soda) and some sodic perchlorate and iodid; hence it forms an important commercial source of iodine.

The mixed mineral mass, called "Caliche," when taken out of the ground is dissolved in water; and the solution boiled down, during which process the common salt is first deposited and is raked out of the pans; the nitrate is afterward farther purified by crystallization. As brought into commerce for agricultural purposes it constitutes a moist gray saline mass, somewhat resembling common salt, of which substance it usually contains a few per cent; occasionally also a small amount of sodic perchlorate (which acts injuriously on vegetation). Aside from its use as a fertilizer, Chile saltpeter serves for the manufacture of nitric acid; and either directly, or after previous transformation into potassic nitrate, for that of gunpowder.

The Chilean locality is the only one from which the commercial article is derived; the deposits elsewhere are too limited in extent to compete commercially with the South American product. Caliche ranging as high as 80% of nitrate of soda has been sent to the writer from the Colorado Desert in Southern California, but the exact locality of occurrence has not been divulged. Extended areas of clay hills impregnated with nitrates exist in the Death Valley region of California, but in the absence or extreme scarcity of water in that region, it is doubtful whether these impregnations can be made practically available. Another locality is that near White Plains, Nevada, where Caliche averaging about 50% purity is found in cavities and crevices of a reddish volcanic rock. The rainfall in this region is so slight that the greater part of the dust or sand blown about by the wind consists of Glauber's salt. Here also, as in Chile, the niter deposits appear to be restricted to within a short distance from the surface, and the total amount thus far observed appears to be insufficient to encourage large-scale exploitation.

Origin of Nitrate Deposits.—The probable origin of these niter deposits has given rise to a great deal of discussion, and a wide difference of opinion exists as to the source from which the nitrogen may reasonably be supposed to have been derived. According to the present state of our knowledge, it must be presumed that its sources have been organic, and that the niter has been produced by the activity of the same bacteria which now produce nitrates in our soils, rendering the nitrogen of humus available to plants. But it is by no means clear what that organic material could have been; for at the present time the plateau of Tarapacà is almost wholly destitute of vegetation, if not of animal life. The latest and apparently most reasonable suggestion is that of *Kuntze*, who calls attention to the fact that the vicuñas and llamas which are at home in this portion of the Andes, and are known to have roamed over that region in countless herds, have the curious habit of always depositing their manure in one and the same place whenever at liberty. Each herd of these animals has its definite dunging place at some convenient point. That such herds have existed in the region from time immemorial is obvious from historical as well as collateral evidence; and as their manure accumulated, its nitrification would progress rapidly under the prevailing arid conditions. The common salt would naturally be derived from the urine and excrements, and the alkaline salts which exist throughout this region as the products of soil decomposition, would be quite sufficient to account for the alkaline bases in the caliche. On the other hand, the presence of iodine points to seaweeds as the organic source.

Intensity of Nitrification in Arid Climates.—Of the efficacy of nitrification under arid conditions abundant evidence may be found within the State of California. In the alkali lands of southern California the nitrates of soda, lime and magnesia are almost universally present; they form at times as much as one-fifth and even more of the entire mass of alkali salts, and in one case the total amount in the soil has been found to reach two tons per acre, with an average of twelve hundred pounds over ten acres. In the plains of the San Joaquin Valley, spots strongly impregnated with niter are found, especially under the shadows of isolated oak trees, where the cattle have been in the habit of congregating for a long time; a case quite analogous to that supposed by *Kuntze* to exist in the Chilean locality. Of course it is only in arid climates that the accumulation of nitrates can usually occur; for in the region of summer rains the nitrates formed during the warm season will inevitably be washed into the subdrainage, unless restrained by absorption by the roots of vegetation. The heavy losses occasionally occurring from this cause in the course of a rainy winter on summer-fallowed land have been amply demonstrated by many investigations.

POTASH MINERALS.—By far the most abundant occurrence of potash in the earth's crust is that in silicates and notably in orthoclase or potash feldspar, which contributes so largely to soil-formation. But in the absence of any economically successful artificial method for producing potash compounds from feldspars on a commercial scale, almost the entire supply of potash salts was, until a comparatively late period, derived from plant ashes, viz., the "potashes" of commerce. At the same time, almost the entire demand for alkalies for industrial uses bore upon the same product, until the invention, toward the end of the last century, or *LeBlanc's* process for the manufacture of soda from common salt; for until that time, soda in the various forms in which it was imported from the Orient or prepared from seaweed ashes, was a comparatively costly product. LeBlanc's invention was most timely in that it very quickly diminished materially the production of potashes which, in view of the increased demand for alkalies for industrial uses, seriously threatened the depletion of agricultural lands, and of woodlands as well, of one of its most essential ingredients. Yet as there are many industrial uses in which soda cannot replace potash, the manufacture of potashes continued to a greater or less extent, as no other available source except the ashes of land plants, was then known. The production of potassic chlorid from the mother-waters of sea salt in the spontaneous evaporation of sea water for the manufacture of common salt, was on too small a scale to influence materially the manufacture of potashes.

Discovery of Stassfurt Salts.—The depletion of potash had become so serious a matter in the agricultural lands of Europe, that for a time much research was bestowed, and prizes offered for an economical method of producing potash salts from feldspar, on a commercial scale. But the problem had not been satisfactory solved when, in the year 1860, attention was called to the fact that the saline deposits overlying certain large rock-salt beds that had been developed by borings near Stassfurt in Prussia, contained so large a proportion of potash salts, as to render their purification and conversion into fairly pure sulphate and chlorid technically feasible. The impulse having been given, the potash industry developed rapidly in that region as well as in the adjacent portions of Saxony, where the same formation underlies; the production of "Stassfurt Salts" rapidly assumed a greater development than that of the rock-salt which had originally prompted the enterprise, and numerous additional boreholes demonstrated an unexpectedly wide extension of the same beds. At the present time, in consequence of such development, the manufacture of potashes from plant ash has almost ceased, outside of Canada and Hungary; and the production of potash salts in the Stassfurt region now supplies the demand of the entire world, both for industrial and agricultural purposes.

The cheapening of potash as a fertilizer has rendered possible the profitable cultivation of large areas of land which were naturally too poor in that substance for ordinary cultures; and has likewise rendered possible the restoration to general culture of lands that had ceased to produce adequately, on account of the depletion caused by long-continued cropping. It has likewise served to intensify agricultural production wherever desired; and between this supply and that of phosphoric acid from the phosphorites (see above), and the discovery of the nitrogen-absorbing power of leguminous plants, which can be used for green-manuring, farmers have been enabled to dispense, in many regions, with the production and use of stable-manure, which until then had been considered an indispensable adjunct to agriculture everywhere. Even within the last fifty years it was proclaimed by high authority in Germany that stable-manure constituted, as it were, the farmer's raw material, from which he manufactured the various products of the field through the intervention of the plant-producing power of the soil.

Origin of the Potash Deposits.—The manner in which this accumulation of potash salts has been formed deserves explanation. It is abundantly evident that nearly all deposits of rock-salt thus far known have been formed by the evaporation of sea-water at times when bays or arms of the sea were cut off from open communication with the ocean. The composition of sea-water has already been given and discussed (chap. 2, p.26); and by the slow evaporation of sea-water on a small scale we can quite successfully imitate the phenomena observed in natural rock-salt deposits. When sea-water is heated a slight deposit of lime carbonate (usually containing a little ferric oxid and silica) is soon formed; and a corresponding thin deposit of ferruginous limestone is commonly found at the base of rock-salt-bearing deposits. Next above this we almost invariably find a deposit of gypsum, sometimes of great thickness; in the artificial evaporation of sea-water the same thing occurs so soon as the brine has reached a certain degree of concentration. It constitutes the major portion of the "panstone" of salt-boilers. Next above follows a deposit of rock-salt, at base somewhat mixed with gypsum; its thickness varies greatly according to circumstances. Above it lie the potash salts.

In the manufacture of sea-salt by evaporation in shore lagoons or "saltpans," the solution remaining after the salt has been deposited (known as "mother-waters," or "bittern"), of course remains on the surface of the salt unless allowed to drain off, as is done in the process of manufacture. When not drained off, the water gradually evaporates, and there remains a saline crust of a composition exactly resembling that of the upper layers at Stassfurt, containing a large proportion of potash salts.

If it be asked why the Stassfurt salts are not found overlying every rock-salt deposit in the world, the answer is that in a great many cases the concentrated mother-waters have had an opportunity to flow off from the surface of the rock-salt by the action of tides, the inflow of fresh water from the land or from other causes. Their presence therefore depends upon the fulfilment of accidental conditions not nearly always realized in the natural evaporation of sea-water, but which happened to occur on a very large scale in that portion of the North-European continent.

Nature of the Salts.—The potash is present in the Stassfurt salts in the form of complex sulfates and chlorids containing, besides, sodium, calcium and magnesium in various proportions and modes of combination. The most abundant of the potassic chlorid minerals is carnallite, a hydrous chlorid of potassium and magnesium. The chlorids characterize chiefly the upper portions of the deposit, the sulfates the lower.

Kainit.—Of the products derived from the Stassfurt salt industry for agricultural use, the two requiring special consideration are "kainit," a natural mixture of the several chlorid minerals in varying proportions; and "high-grade sulfate." Being a natural product, "kainit" is the cheapest source of potash available to the farmer; but on account of its variability in composition it must be sold and purchased on guaranteed assay. On account of its large content of chlorin it is not desirable in the production of certain crops, especially in the arid region, where alkali soils, and even those not visibly alkaline, often contain already large amounts of chlorin. Moreover, kainit usually contains a considerable proportion of common salt. For the arid region therefore the sulfate is generally preferable, although it is somewhat higher in price for the same amount of potash. The potash content of commercial kainit (calculated as K_2O) ranges from 16 to 35%, while the sulphate frequently ranges from 80 up to 95% of the pure sulfate; thus costing materially less in freight charges than the lower-grade kainit. Its potash content ranges from 43 to over 50% of K_2O.

Potash Salts in Alkali Soils.—The sulfates and chlorids of potassium, however, occur not only in connection with rock-salt deposits, but are also found in the alkali soils of the arid region. They are, in fact, never absent where such salts occur at all, and their percentage in the total of salts ranges all the way from about 4 to as much as 20% of potash sulphate. In numerous cases it has been found that the content of this salt to the depth of four feet amounts to from 1200 to 1500 pounds per acre. In such lands, of course, additional fertilization with potash salts is totally uncalled for, the more as such soils invariably contain, besides the water-soluble potash, an unusually large percentage of the same in the form of easily decomposable silicates, or zeolites.

Farmyard or Stable Manure.—In connection with the subject of mineral fertilizers, it will be proper to discuss briefly the uses and special merits of stable manure, composts, etc. Up to within the last century, these were practically the only fertilizers known and used, and the exclusive use of this manure might have continued indefinitely but for the discovery that as time progressed, stable manure and with it grain crops, for the production of which it was necessary, became less and less in amount, so as to threaten bread famines. The cause of this diminution was, of course, the incompleteness of the return of the soil-ingredients taken off by the crops, when these were exported to feed the cities or foreign countries. Thus the attention of chemists, and notably that of Liebig, was attracted to the solution of the problem of keeping up production even with an insufficient supply of stable manure; and the discovery of the use of mineral fertilizers was the result of their activity.

The chemical composition of stable manure does not, alone, suffice to explain its remarkable efficacy and the difficulty of replacing it by any other material. The composition of manure of course differs not only with different animals but also with the different feeds consumed by them; but the average composition of farmyard manure is approximately given thus by Wolff and others:

ANALYSES OF VARIOUS FARMYARD MANURES.

	1.	2.	3.	4.	5.
Water	71.00	75.00	79.00	79.95	72·33
Dry Matter	29.00	25.00	21.00	20.05	27·67
Ash ingredients	4.40	5.80	6.50	....	5·87
Potash	0.52	0.63	0.50	0.84[1]	0·69
Lime	0.57	0.70	0.88	....	0·85
Magnesia	0.14	0.18	0.18	....	0·14
Phosphoric acid	0.21	0.26	0.30	0.40	0·30
Ammonia	....	....	....	....	0·02
Total Nitrogen	0.45	0.50	0.58	0.78	0·46

1. Average composition of fresh farm manure (Wolff).
2. Average composition of moderately rotted farm manure (Wolff).
3. Average composition of very thoroughly rotted farm manure (Wolff).
4. Mixed cow and horse manure from a bed two feet thick, accumulated during the winter in a large covered yard, and packed solid by the tramping of cattle (The analysis by F. E. Furry).
5. "Box Manure," consisting of mixed manure of bullocks, horses, and pigs (Way, Royal Agric. Soc. Journ., 1850, II., 769).

It is thus seen that the percentage of the important plant-foods in stable manure are minute when compared with those commonly found in "commercial" fertilizers. Nor are they so much more available for plant absorption than the latter; a very large proportion is not utilized at all the first year, and unless the amount applied is very large it hardly carries the supply needed for the usual crops.

It is now well understood that its efficacy is largely due to the important physical effects it produces in the soil. It helps directly to render heavy clay soils more loose and readily tillable. If well "rotted" or cured it also serves to render sandy, leachy soils more retentive of moisture; and the humus formed in its progressive decay imparts to all soils the highly important qualities discussed later on (chapt. 8). More than this, the later researches have shown that stable manure acts perhaps most immediately upon the bacterial activity in the soil, greatly increasing it not only directly by the vast numbers of these organisms it brings with it, but also in supplying appropriate food for those normally existing in the soil (see

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[1] And soda.

chapt. 9). In so doing it serves indirectly to render the soil ingredients more available, and to impart to the soil the loose condition required in a good seed-bed—a "tilth" which cannot be brought about by the operations of tillage alone.

The only possible substitute for the use of stable manure is found in green-manuring with leguminous crops conjointly with the use of commercial or mineral fertilizers. Unless this is done the use of the latter, alone, ultimately leads to a depletion of humus substances, which renders the acquisition of proper tilth by the seed-bed impossible, and causes a compacting of the surface soil which no tillage can remedy.

Proper method of using stable manure in humid and arid climates.—In the humid region it is a common practice to spread the stable manure on the surface of the fields and leave it there without any special operation to put it into the soil; trusting to the rains, earthworms and subsequent tillage for its being brought into adequate contact with the roots; it is rarely plowed in. In the arid region this mode of using it is impracticable; it would remain on the surface indefinitely without advancing in its decay because of the dryness, and unless plowed in very deep the ordinary, strawy manure would ruin the seed-bed by rendering it too pervious to the dry air, thus preventing germination. Much of this valuable material has therefore been, and to some extent is still being burnt, thus causing a severe depletion of the land, both of humus and of mineral plant-food. The best way to deal with stable manure in the arid regions is to thoroughly rot or cure it before putting it on the land, and then plowing it in. To do this of course it must be put in piles and wetted regularly; a procedure which at the high prices of labor is thought to be too expensive, but which in the end would be found eminently profitable, unless green-manuring is regularly done. The very small proportion of humus generally present in arid soils renders this precaution indispensable, if production and proper tilth is to be maintained. The saving of stable manure and of all composting material, even if less needful as a means of supplying plant-food in the rich soils of the arid regions, is fully as essential in order to maintain the humus supply.

(B.) MINERALS UNESSENTIAL OR INJURIOUS TO SOILS.

The minerals heretofore mentioned contribute to soil formation either one or several ingredients, important to plant growth either by their mechanical or chemical action. It remains to consider some not intrinsically desirable, but frequently present in certain soils, which should be known to the farmer in order that he may be enabled to counteract or remove their injurious effects. Leaving aside such as are of only casual or rare occurrence, the following may be mentioned as among those which not unfrequently affect soils desirable for culture to such extent as to make them unavailable for general farming purposes:

Iron Pyrites; sulphid of iron containing two molecules of sulphur to one of iron; a mineral exceedingly common in deposits of metallic ores, and whose deceptive gold-like color has caused it to be mistaken for gold so often as to cause it to be designated as "fool's gold" among miners. While it frequently does contain some gold and is often associated with valuable ores, it is practically valueless when occurring outside of mineral veins, in rock masses; and more especially in sedimentary rocks, such as sandstones, limestones, shales and clays.

When present in soils it sometimes becomes a source of trouble to the farmer, because in contact with air it is soon transformed into ferrous sulfate or copperas, which, like the carbonate referred to above, is injurious to plants. Sometimes indeed iron pyrites is actually *formed* in badly-drained soils alongside of the carbonate of iron, when much sulfate (such as gypsum) is present; and then its injurious effects subside more slowly than do those of the carbonate (see above, p. 46).

Recognition of Iron pyrites.—The mineral is easily recognized by its golden or brass-yellow tint; the latter color being the one most commonly shown in the "sulphur balls" occurring in marls or soft limestones. A very easy test is to pulverize it and then heat it on a shovel over a fire, when it will soon itself take fire, burning with a blue sulphur flame, and upon more complete roasting, leaving behind a red powder, viz., "Venetian red" or red ochre; that is, ferric oxid. In clays it commonly occurs in large, well-defined cubes, which do not readily form copperas but rather become covered with a crust of limonite or brown iron ore.

When a subsoil is found to contain pyrites, or when "sulfur balls" have been accidentally introduced with dressings of marl, the remedy is thorough and persistent aëration of the material. In the case of marls nothing more need be done; but in that of ill-drained subsoils it is best to add lime in moderate dressings, to accelerate the transformation into ferric hydrate or iron rust, and gypsum; whereby the copperas becomes not only innocuous but adds two beneficial ingredients to the soil. The same policy will render available manure or other materials which have been disinfected by means of solution of copperas.

Halite (rock-salt), or common salt, has already been mentioned as to its occurrence in connection with the Stassfurt potash salts (see above, page 71); but as rock-salt it rarely exerts any injurious influence upon lands. It is, however, a common ingredient of seashore lands, and is also present to a certain extent in the alkali lands of the arid countries. While it is true that occasionally small quantities of common salt are used as an ingredient in fertilization, its usefulness in that direction is exceedingly subordinate; and it is far more generally to be considered as an injurious ingredient of all cultivatable soils whenever present to a larger extent than a few hundredths of one per cent. It is usually considered that one-fourth of one per cent of common salt renders lands unfit for most culture plants. Only a few, such as asparagus, the beet, the saltbushes and some others, succeed when it is present in this or in larger amounts. In the case of sea water it is usually accompanied by a still more injurious ingredient, magnesic chlorid or bittern; which is detrimental to plant growth in much smaller quantities than the common salt itself.

Recognition of Common Salt.—The presence of common salt may, as a rule, be detected by the taste, well-known to every one; when this taste is very intense or somewhat bitterish, it indicates the presence of bittern. The presence of salt, however, is easily verified without the use of chemical reagents, by slowly evaporating some of the clear water leached from the soil in a clean silver spoon. If the last few drops are allowed to evaporate spontaneously, it will be easy to distinguish, even with the unaided eye, the square, cubical crystals, sometimes combined into cross-shape, which are characteristic of common salt. It is always an unwelcome addition to the land, and as its action cannot be neu-

tralized in any way, it can be gotten rid of only by leaching-out. This process is usually accomplished in seashore lands by the action of rain, or by the overflow of fresh-water streams, after the tide has been excluded by means of drains provided with check-valves to prevent the inflow of tidewater; or else by underdrainage, and flooding when possible.

Mirabilite, (Glauber's salt) or sulfate of soda, exists not unfrequently in the soils of the arid region and sometimes encrusts extended areas of lowlands during the dry season. When present in the soil it will commonly be seen blooming out on the surface after a rain, in light, feathery, needle-shaped crystals, sometimes to such an extent that it can be collected by the handful. Subsequently, when wafted by the wind, it is reduced to a fine white dust, which constitutes a goodly proportion and sometimes the entire mass of the "alkali dust" that is so annoying on the plains of Nevada, and in the desert regions generally, during the hot summer. Near White Plains, Nevada, it forms a thick layer of "*white sand,*" in which the foot sinks deeply, and which is carried about by the wind with great ease.

Glauber's salt is never a desirable soil-ingredient. It is largely produced as a by-product in several industries, but cannot be utilized for agricultural purposes to any extent. It is, however, much less injurious to plant growth than common salt; according to experience in California it may be considered about three times less so. It constitutes the major portion of what is commonly known as "white alkali," which is well known to be much less injurious to crops than the "black" kind, which contains carbonate of soda.

Trona and Urao are natural forms of carbonate of soda or salsoda. Like Glauber's salt, it commonly occurs as a surface efflorescence or crust in dry or desert regions; either from the evaporation of standing water, as in the case of the soda lakes of Nevada, Hungary and Egypt, or as an efflorescence on the surface of the soil, as in the western United States, Mexico ("urao"), North Africa ("trona"), and at many points in the Old Continent. In the United States it is commonly known as "black alkali," because of the black spots formed on the surface by evaporation; practically the same name ("kara") is given it in Arabia and Asia Minor, whence impure soda has long been imported into Europe; while in north India it forms part of the "reh" salts that incrust large areas (usar lands) in the Indo-Gangetic plain.

The natural mineral always contains an excess of carbonic acid over the "normal" salt, nearly in the proportion of four parts of carbonic dioxid to three of soda; it is sometimes designated as sesqui-carbonate. In hot sunshine it may lose most of this excess for a time; while within the soil itself it may, in presence of abundant carbonic acid, become temporarily converted wholly into hydrocarbonate or "bicarbonate," which is less corrosive than the monocarbonate or common salsoda.

Injury caused in soils.—Like common and Glauber's salt, carbonate of soda is always an unwelcome soil ingredient; more so, in fact, than either of the other two, since less than a tenth of one per cent is sufficient to render certain soils wholly untillable, by the deflocculation or puddling of the clay; at the same time rendering it impervious to water. It is by far the most injurious ingredient that ordinarily occurs in otherwise good, arable soils; for in addition to the physical effect just mentioned, it dissolves the humus-substance of the soil, forming an inky-black solution which, especially when evaporating on the surface and forming black spots, has given rise to the popular name of "black alkali." As will be more fully explained hereafter, wherever such is the case, the first step necessary toward reclamation is the transformation of the carbonate of soda, at least in part, into the relatively innocuous sulfate, by means of gypsum in the presence of water; while carbonate of lime remains in the soil.

In its direct action on the plants themselves, soda is also most injurious; as when accumulated to any extent near the surface by evaporation it will corrode the root-crown or stem, and sometimes completely girdle the same, destroying the bark. Farther details on this subject are given in chapter 22.

Epsomite, or Epsom salt, or sulfate of magnesia, is another one of the water-soluble minerals frequently found efflorescent on the surface of the ground; more commonly in saline seashore lands than in the alkali region proper, although it is rather common in the northeastern portion of the arid region of the United States. Whether on the soil surface or in the crevices of rocks, its needle-shaped, feathery crystals greatly resemble those of Glauber's salt, but are readily distinguished by the more intensely bitter taste. Epsom salt is frequently the last remnant of sea-salts left in the soil after reclamation. Though probably somewhat more injurious to plant growth than Glauber's salt, the mineral Kieserite, one of the Stassfurt salts and consisting essentially of Epsom salt, is sometimes used as an application to calcareous lands instead of gypsum, and with good results. Yet gypsum is usually the safer, and equally effective.

Borax (bi-borate of soda) occurs much more rarely than the salts just described; most frequently in certain portions of California, forming part of the "alkali" in the soil. It is injurious to plant growth, but is as readily dealt with as is the carbonate of soda, by dressings of gypsum, whereby inert borate of lime is produced.

It is hardly necessary to say that saline waters containing any of the above salts in notable amounts must be used for irrigation very cautiously. The measures to be observed in this respect will be discussed later.

PART SECOND.

PHYSICS OF SOILS.

CHAPTER VI.

PHYSICAL COMPOSITION OF THE SOILS.

As has already been stated (chapt. 1, p. 10), the general physical constituents of soils are *rock powder or sand* and *silt*, more or less decomposed according to the nature of the original rocks; *clay*, the product of the decomposition of feldspars and some other silicates; *humus*, the complex product of the decomposition of vegetable and animal matters on and in the soil mass; as well as vegetable matter not yet humified. Each of these several constituents must now be considered more in detail. Since clay is the substance whose functions and quantitative proportions influence most strikingly the agricultural qualities of land, it should be first discussed.

Clay as a Soil Ingredient.

The plasticity and adhesiveness of clay, together with the extreme fineness of its ultimate particles (said to reach the 1-25000 of an inch), explains its great importance as a physical soil ingredient. It serves to hold together and impart stability to the flocculent aggregates of soil particles that compose a well-tilled soil; for without clay the sand would collapse into close-packed single grains so soon as dried, and loose tilth would be impossible. Sand drifts illustrate this condition.

On the other hand, the fineness of the particles serves to render clay very retentive of moisture as well as of gases and of solids dissolved in water, imparting these important properties to soils containing it; while coarse sandy soils are oftentimes so deficient in them as to render them unadapted to any useful culture, despite the presence of an adequate supply of plant-food.

When to these essential physical properties of clay, there is added the fact that usually the clay-substance as it exists in soils contains the most finely pulverized and most highly decomposed portions of the other soil-minerals, and therefore the main part of the available mineral plant-food, it is easy to understand why soils containing a good supply of clay should be called and considered " strong " land by the farmers of all countries. " Poor " clay soils are exceptional; but sometimes the clay content reaches such a figure that the difficulties of tillage render them too uncertain of production for profitable occupation.

Amount of Colloidal Clay in Soils.—Any and all of the kinds of clay mentioned (p. 57) as occurring naturally may, of course, enter into and form part of soils. But as the amount of true, plastic clay substance contained in them is very indefinite, it becomes necessary, in order to classify soils in respect to their tillableness, to ascertain more definitely the amount of pure, or nearly pure, colloidal clay substance contained in the several classes of soils ordinarily recognized and mentioned in farming practice. That this determination can at best be only approximate, is obvious from the fact mentioned above (chapt. 4, p. 59), that pure kaolinite itself is not plastic, and only becomes so by the indefinite comminution and hydration it experiences in the processes of soil-formation. As the progress of this process is also indefinite, the same soil containing particles ranging from the finest to the chalky scales of pure kaolinite, the drawing of a line must be more or less arbitrary and empirical.

From numerous experiments and comparisons made, the writer has been led to place the limits of "plastic clay" at and below such grain sizes as will remain suspended (afloat) in a water column eight inches high, during 24 hours. To go beyond this point in the examination of soils for practical purposes, would render such examinations so laborious and hence so rare, that this kind of work would be practically excluded from ordinary practice. According to this view the following percentages of such " clay " correspond approximately to the designations placed opposite:

Very sandy soils	.5 to 3%	clay
Ordinary sandy lands. . .	3.0 to 10%	"
Sandy loams.	10.0 to 15%	"
Clay loams	15.0 to 25%	"
Clay soils.	25.0 to 35%	"
Heavy clay soils	35.0 to 45%	and over.

It must be distinctly understood, however, that these figures make no claim to accuracy or invariability. For, the tilling qualities of a soil containing one and the same amount of such "clay" may be very materially modified according to the kind and amount of each of the several grain-sizes of rock powder or sand they contain.

Influence of fine powders on plasticity and adhesiveness.—An admixture of a large amount of fine powders diminishes materially the adhesiveness of a clay soil, even though it may render it even more "heavy" in tillage; while the admixture of coarse sand, even in very considerable proportions, does not greatly influence the adhesiveness of the clay. The latter alone cannot therefore serve as a proper guide or basis for the classification of soils in respect to tillage; we must also take into consideration the nature and amount of the several granular sediments mixed with it.

Moreover, the nature and especially the adhesiveness of the clay substance as obtained by analysis may vary considerably in the presence of a very large amount of the finest grain-sizes; among which ferric hydrate or iron rust is especially apt to accumulate predominantly in the clay, considerably increasing its apparent weight and greatly diminishing its adhesiveness.[1] In strongly ferruginous soils, therefore, it becomes necessary to take into special consideration the amount of the ferric hydrate or rust which accumulates in the clay substance. The presence of large amounts of humus or vegetable mold also influences materially the adhesiveness and physical properties of the clay obtained by the method described, although most of it remains with the finer powdery sediments or grain-sizes. There are, besides, other colloidal or at least amorphous substances present in all soils, such as silicic, aluminic and zeolitic hydrates, which are all non-plastic, and yet sufficiently fine to form part of the "clay" obtained as above specified.

Despite these imperfections, (which however can in a measure be taken into consideration in judging of a soil's tilling qualities by its clay content), the figures given in the above table approximate much more nearly to a tangible basis for such estimate, than the utterly indefinite mixtures which under the older methods of analysis have been, and still are to some extent, used as a basis for soil classification by writers on agriculture.

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[1] This fact emphasizes the impossibility of explaining the plasticity and adhesiveness of clay simply as a function of fineness of grain.

Rock Powder; Sand, Silt and Dust.

The powdery (sandy and silty) constituents of soils usually constitute the greater part of their mass; and the proportions present of the several grades of fineness exert a most decisive influence upon their cultural qualities, and very commonly upon their agricultural value also. It is needless to add that the kind of mineral of which they consist or from which they were formed, is also of great importance in determining the quality of soils from the standpoint of the chemist, with respect to their content of mineral plant-food.

WEATHERING IN HUMID AND ARID REGIONS.

Sands of the Humid Regions.—As has already been stated, " sand " is usually understood to be, in the main, quartz more or less finely pulverized, generally intermingled with a few grains of other minerals. With this understanding, since quartz is practically inert with respect to plant nutrition, it follows that soils consisting mainly of this substance contain but little plant-food; hence the common expression "poor, sandy land," the outcome of the experience had in Europe and in the Eastern United States, and which until recently has been held to be of general application. The " sands of the desert " have, both in ordinary life and in poetry, always stood as the symbol of sterility.

Thus the sandy lands ("sand hammocks") of Florida, the (long-leaf) pine lands of the Gulf States, the " pine barrens " of New Jersey and of Michigan, are noted both for their sandy soils and their sterility. after brief cultivation; necessitating fertilization within a few years from the time of occupation. In Europe, the " Heide " (heather) soils of northeastern Germany are of the same cultural character.

Sands of the Arid Regions.—The experience of arid countries however, has long ago shown that some very sandy lands —*e. g.*, such as form the oases of the north African deserts— may be extremely productive when irrigated, and also of considerable durability. Actual experience and close investigation given this subject in the arid regions of the United States has fully demonstrated that lands appearing to the casual observer to be hopelessly sterile sandy deserts, very commonly prove to be even more productive than the more clayey lands of the same regions. Examination of the sand shows, in these cases, that instead of mere grains of quartz, the minerals of the parent rock, partially decomposed, themselves constitute a large proportion of the sandy mass. But in the regions of deficient rainfall, as has already been stated, (p. 47) the formation of clay (kaolinization) is exceedingly slow; hence the decomposition of the rock powder results in the production of predominantly pulverulent instead of clayey soils. But the mineral plant-food is not on that account less available, provided other physical conditions necessary for the success of plant growth are fulfilled. Among these moisture stands foremost; hence the relative proportions of the several grain-sizes are of vital importance, since upon this depends to a great extent the proper supply and distribution of moisture, without which no amount of plant-food will avail. Moreover, the finest and most highly decomposed powder is the portion from which the roots draw their chief food-supplies.

The point last mentioned is well shown in the results obtained by Dr. R. H. Loughridge, from the analysis of each of the several grain-sizes into which he had resolved a very generalized soil of the State of Mississippi, representing a very large land area in that State as well as in Tennessee and Louisiana. The details of this investigation are given farther on; but summarily it may be stated that he found practically the whole of the acid-soluble mineral plant-food accumulated within the portion of the soil the fineness of whose grains was below .025 millimeters (one-thousandth of an inch); ingredients so fine as to be wholly impalpable between the fingers. Moreover, two-thirds of the total amount was found in the portion described above as "clay." It is thus readily understood why clay soils are in the regions of summer rains commonly designated as "strong" lands.

The corresponding later investigations of Rudzinski (Ann. Agr. Inst. Moscow, Vol. 9, No. 2, pp. 172–234; Exp. Sta. Record, Dec. 1904, p. 245) and of Mazurenko (Jour. Exp. Landw. 1904, pp. 73–75; Exp't Stn. Record, Dec. 1904, p. 344) fully corroborate Loughridge's conclusions, for typical soils of European Russia.

In the arid or irrigation regions, however, the case is different, for the reason that much of the decomposed rock-substance remains adherent to the surface of the larger grains, and plastic clay is formed to a much less extent. Much available plant-food may therefore, in arid lands, be present even in rather coarsely sandy soils almost devoid of clay; such as in humid climates would he likely to be found wholly barren. (See chapt. 19).

PHYSICAL ANALYSIS OF SOILS.

Use of Sieves.—Down to a certain point the separation of the soil into its several grain-sizes may be accomplished by means of sieves. We may thus separate coarse gravel from fine gravel and from sand; and the latter may itself be separated into several sizes by the same means. This presupposes, of course, that the soil has been previously prepared for the purpose by crushing the lumps consisting of aggregates of finer particles, that in the operation of tillage would again be resolved into their fine constituents, or be penetrated by roots. But this preparation of the soil for sifting must not be carried beyond the point mentioned, for a grain consisting of particles somewhat firmly cemented together will under ordinary conditions play in the soil precisely the same part as a solid sand-grain, and must not therefore be broken up, if the soil is to be examined in its natural condition. The pressure of the fingers or of a rubber pestle is as far as trituration should go. The disintegration of these compound particles by means of acids, as prescribed and practiced by the French soil chemists, may wholly change the physical nature of the soil by the breaking-up of mechanical aggregations which in the usual course of tillage would remain intact. This is especially true of strongly calcareous soils, and particularly those containing calcareous sand.

The sieves used for this purpose should not be ordinary wire sieves, but should have bottoms of sheet brass perforated by *round* holes of the various diameters desired, of fractions of inches, or preferably of millimeters. For the finer grain sizes, silk bolting cloth is used by the U. S. Bureau of Soils.

In the sifting process it will be found that so soon as the finer grain-sizes of the sand are approached, the sieve fails to act satisfactorily; the more so, the more clay was originally contained in the material.

The fine particles flock together, forming little pellets, which refuse to be separated by the sieve. This difficulty can, of course, be partly overcome by previously separating the clay from the sand by means of water, as detailed above; but even then it will be found that so soon as the grain-sizes fall much below $\frac{1}{50}$ of an inch ($\frac{1}{2}$ millimeter) the same difficulty is experienced, so long as the sand is dry. By playing a small stream of water upon the sieve, however, all the particles beyond the $\frac{1}{500}$ of an inch may be successfully separated from the coarser portion; and for many practical purposes the separation need be carried no farther.

Use of Water for Separating Finest Grain-Sizes.—The scientific investigator, however, must of necessity proceed to separate the finer grain-sizes from each other, since, as will presently be shown, they influence the tilling qualities of the soil to a much greater degree than do the coarser particles. Such farther separation can be accomplished only by the aid of water.

Subsidence Method.—When a small amount of soil is stirred up in water, and is afterward allowed to stand for some time, the different grain-sizes will settle consecutively in accordance with their sizes (or weights); the smallest ones settling latest, and the clay only remaining suspended, as stated above. So long, however, as any considerable amount remains suspended in the water, the latter is not only denser but especially more viscid than if the clay were absent. In order therefore to obtain correct results by any method involving the use of water, it is necessary to remove the clay before proceeding to the separation of the granular sediments. This, as has been already stated, is approximately accomplished by allowing the soil, when diffused in water after proper disintegration, to settle for 24 hours from a column of water 200 mm. high, whereby all grain-sizes, of and above .01 mm. diameter are removed from the turbid liquid. This sedimentation is then repeated until after 24 hours the water becomes clear. The clay is then determined in the "clay water" by evaporation or precipitation; the granular sediments may then be successfully separated by sedimentation.

The U. S. Bureau of Soils uses for the separation of clay, instead of subsidence for 24 hours, the more expeditious process of contrifuging the turbid soil water in appropriate glass cylinders, by the aid of an electric motor; and thus in a relatively short time obtains "clay" in which the upper limit of size is one-half of that mentioned above, viz., .005 mm. But for the costliness of the appliances required, including the entire time of an operator, this method of separating the clay would undoubtedly be preferable to the elimination by subsidence; the more as a more minute grain-size for the clay group is thus secured.

The separation of the clay having been accomplished, the various sizes of silt and sand may be separated by again suspending them in water; and interrupting the settling process at stated times, the grain-sizes corresponding to definite velocities in settling may be segregated and weighed. When this process of settling and decanting is carefully and repeatedly carried out, very good results are obtained.

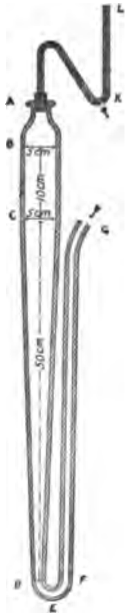

FIG. 6.—Schöne's Elutriator.

Hydraulic Elutriation.—The sedimentation (or "beaker") method, long practiced in the arts is, however, quite tedious, requiring the constant close attention of a skilled observer. The desired results may, in the writer's judgment, be more conveniently obtained by the hydraulic method, whenever no very large volume of work of this kind is required to be done at once.

When instead of allowing the soil to settle in quiet water, the latter is used as an ascending current of regularly graded velocities, it is clear that the soil particles will be carried off by this current in exact conformity with their several sizes (or strictly speaking, volume-weights); and when maintained in such a current for a sufficient length of time, the entire quantity of the sediment corresponding to the prevailing velocity will be carried away. It is of course easy to ascertain to what grain-sizes certain velocities of the upward current (regulated by a stopcock with arm moving on a graduated scale) correspond, and to regulate accordingly the intervals between the different velocities to greater or less detail, as may be desired. A number of instruments have been devised for this purpose.

Schöne's Elutriator is the one commonly used in Europe;

in it the upward current ascends in a conical glass tube, (see figure 6) entering through a narrow, curved inlet tube, in which the soil sample is kept agitated by the current itself. The objection to this plan is twofold: first, the narrow, curved inlet-tube is readily clogged by the soil mass at the lower velocities, which are thereby changed, so that, unless a very small amount of soil only is employed, the whole mass is not kept properly stirred; second, the circulating currents brought about by the conical shape of the tube cause the sediment-particles to coalesce into complex, larger ones (floccules), which will then settle down and fail to pass over at the current-velocity corresponding to their individual component parts.

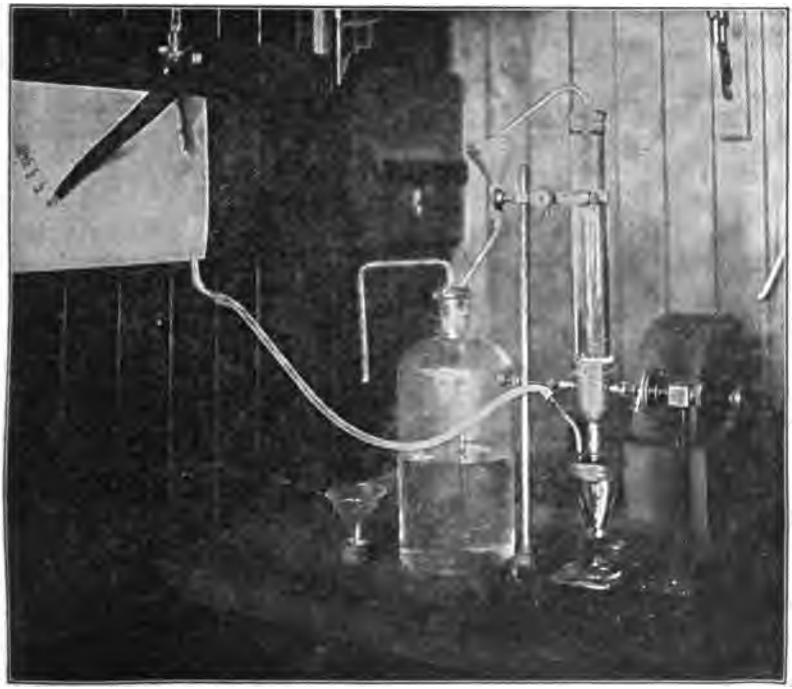

FIG. 7.—The Churn Elutriator (Hilgard's) for the physical analysis of soils.

Churn Elutriator with Cylindrical Tube.—The errors just alluded to are obviated by an arrangement devised by the writer, in which a rapidly-revolving stirrer, placed at the base of a cylindrical tube in which the washing process is conducted and which eliminates counter-currents, continually disintegrates these compound particles, and thus enables the entire quantity of the sediment corresponding to the prevailing current-velocity to pass off with a comparatively slight expenditure of time on the part of the operator (see figure 7). A wire screen interposed between the churn and cylindrical glass tube prevents communication of the whirling motion to the column. As the apparatus works automatically, the analyst has only to observe from time to time whether or not the turbidity near the top of the tube has disappeared; and as the sediment accumulates at the bottom of the tall receiver bottle,[1] no harm is done if the attendant should neglect to change the velocity in time, except that water will run to waste.

The conical relay glass below the churn serves to retain the coarser grades of sediments which are not concerned in the velocities employed in the elutriator tube, and thus prevents injurious attrition. But these sediments can at any time be stirred up by the incoming current and brought into the washing tube if desired. In the same manner the passing-off of the finer sediments can be materially accelerated by running off rapidly about two-thirds of the turbid column of water every twenty minutes.

It should be fully understood that prior to attempting such separation, the " colloidal clay " must first be removed by the subsidence or centrifugal method, since otherwise much larger grain-sizes may be carried off at a given velocity.

Yoder's Centrifugal Elutriator.—A very ingenious instrument which combines the elutriation and sedimentation processes into one, has been devised by P. A. Yoder, of the Utah Expt. Station. The elutriator bottle is placed in a centrifuge driven by an electric motor; it is closed by a glass stopper carrying a delivery tube to a short distance above the bottom of the elutriator bottle, as well as an outflow tube ending at the base of the stopper; the latter also carries a funnel coinciding with the center of rotation. Into this funnel flows gradually

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[1] The figure given of this elutriator in Bulletin No. 24, on physical soil analysis, published by the U. S. Bureau of Soils, shows as the receiver a bottle entirely too low to insure the complete retention of the sediments by settling. The receiving bottle should not be less than twelve inches high and five inches wide.

the muddy water containing the soil in suspension; and the rate of its flow, together with the velocity of rotation, determines the size of the sediment-granules that will be deposited in the slack-water below the mouth of the delivery tube. The muddy soil-water is kept agitated in a funnel-shaped reservoir by air-bubbles from a constant-pressure chamber.

While the principle of this instrument is good, it is quite complicated and the results obtainable from it in practice have not as yet been made public. The inventor claims that an analysis may by its means be completed in less than three hours.

In all hydraulic elutriators a provision for constant pressure in the reservoir supplying the current of water is needed; although in Schöne's and some other instruments a gradually decreasing pressure in a plain reservoir is employed. A large glass bottle or carboy fitted with the proper tubes so as to constitute a Mariotte's bottle (in which the air enters near the bottom of the vessel), is a very convenient arrangement.

Number of Sediments.—The number of grain-sizes or sediments into which the soil mass is to be segregated is of course entirely within the option of the operator. Experience has shown that it is unnecessary to discriminate very closely between the several sizes of the coarser portion of the sand, such as those lying between one-fourth and one-half of a millimeter. But below this point, and especially between one-tenth of a millimeter and the clay, a proper discrimination becomes very important. The series first devised by the writer in 1872 is based upon a consecutive doubling of the velocities of the current from a quarter of a millimeter per second to thirty-two millimeters per second; the sediment of sixty-four millimeter-velocity corresponding to a diameter of one-half of a millimeter, will remain in the elutriator. Above this, as before remarked, the sieve (especially when aided by a jet of water) effects a satisfactory segregation.

The table below shows the elements of these series both as regards current-velocities and maximum quartz-grain diameters carried off by each. In a great many cases, however, it is altogether unnecessary to go into such detail, and a subdivision into six or seven divisions is quite sufficient. Such a subdivision, based upon the doubling of grain-sizes instead of current-velocities, has been adopted by Prof. Milton Whitney, of the U. S. Department of Agriculture, and others.

TABLE OF DIAMETERS AND HYDRAULIC VALUES OF SEDIMENTS.

Designation of materials.	Velocity per second, or hydraulic value.	Maximum diameter of quartz grains.
	Mm.	*Mm.*
Grit	(?)	1–3
Sand	(?)	.5–1
	32–64	.50
	16–32	.30
	8–16	.16
	4– 8	.12
Silt	2– 4	.072
	1.0– 2	.047
	.5– 1	.036
	.25–0.5	.025
	0.25	.016
	< 0.25	.010
Clay	◁ 0.0023	....

Results of such analyses.—A tabular presentation of the results of analyses made in accordance with the above plan will give a good idea of the differences between the various grades of soils recognized in farm practice, to any one accustomed to the study of figures. But a much more satisfactory showing is made by placing the several grain-sizes segregated, into small vials or tubes of identical diameter and placing them in parallel series alongside of each other.[1] The curves formed by the surfaces of the several sediment-columns in each series show to the eye very strikingly the relations of the several grades of soils to each other, and suggest at once that while gentle slopes or gently undulating curves belong to soils of intermediate, loamy character, steep grades and zigzags show soils of extreme types. This is exemplified in the subjoined Figures:

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[1] Convenient stands for this purpose, used by the writer since 1872, may be cut from L-shaped moldings of wood, such as can be readily ordered from any planing mill. The vials can be cemented, wired or tied.

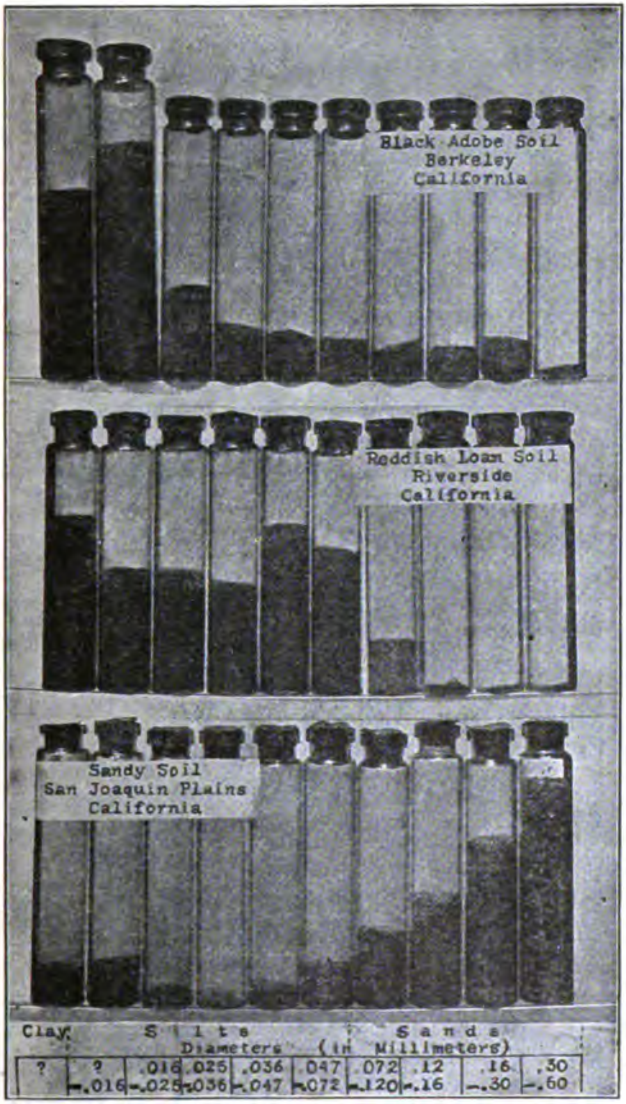

FIG. 8.—Illustration of Results of Hydraulic Elutriation, showing extremes of soil texture, and intermediate loam.

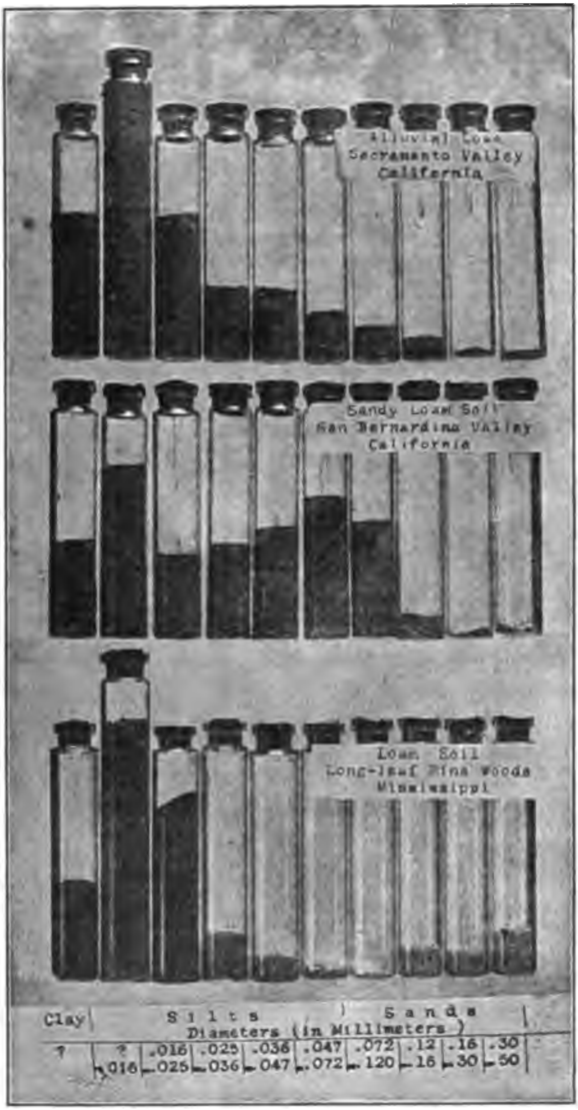

FIG. 9.—Illustration of Results of Hydraulic Elutriation, showing Alluvial Silts and Pine-Woods Soil.

Physical composition corresponding to popular designations of Soil quality.—The subjoined table illustrates the physical composition of a number of soils from the State of Mississippi, selected for their representative character, in order to deduce therefrom approximate definitions of physical character corresponding to popular designations. This table, published in 1873 in accordance with results obtained during the two preceding years, does not require any material modification on account of subsequent investigations. It lacks, however, a characteristic representative of the predominant soils of the arid region, viz., the silty soils so prevalent in dry climates, only approximately represented by No. 165 of the table; hence two such, from California, exemplifying respectively the valley deposits of the Sacramento and Colorado rivers, have been added to the list.

It must not, however, be understood that these typical soils necessarily represent correctly the physical constitution of all soils falling under the same popular designation; for we are far from being able as yet to predict accurately in every case the tilling qualities of a soil material from its physical composition. To do this it would be necessary not only to know with some degree of precision the several physical coefficients of each of the several grain-sizes, and perhaps of many more intermediate ones; but we would also have to construct a formula according to which each could be given its proper weight when present in varying proportions, and of varying shapes, surface condition, and material. For this our present knowledge is wholly inadequate, if indeed the problem is not beyond the limits of mathematical computation. We must for the present at least be satisfied with the empirical approximations afforded us by the constantly increasing number of such analyses, correlated with farming experience.

Since the finest grain-sizes above those classed as "clay" do not tend to "lighten" soils, but even to render them more intractable (" putty soils"), while coarser ones gradually change the dense clay-texture into the "loamy," it is clear that in between there must be a neutral point, some grain sizes which by themselves do not influence soil texture either way. Discussion of numerous physical analyses, and some direct experiments, have led the writer to conclude that this theoretically neutral grain-size lies at or near the diameter of .025 mm., or .5 mm. hydraulic value. In correlating the results of analysis with the tilling qualities of the soil as to "heaviness and lightness," therefore, that grain-size may usually be left out of consideration.

PHYSICAL ANALYSES OF SOILS AND SUBSOILS.

Designation of Materials.	Diameter (Millimeters).	Velocity (Hydr. V.)		MISSISSIPPI UPLANDS.											MISSISSIPPI RIVER BOTTOM.							CALIFORNIA.	
				Sandy.			Loam.			Clay.				Swamp	River.	River Deposit.			Delta.		River Deposit.	
			238	248	165	206	209	397	219	173	230	246	196	390	237	365	377	395			10	506
		Millimeters. Per second.	White Pipe-Clay. Tishomingo Co.	Tallahoma Subsoil. Jasper Co.	Flatwoods Soil. Chickasaw Co.	Pine Hill Soil. Smith Co.	Pine Hill Subsoil. Smith Co.	Oxford Subsoil. Lafayette Co.	Table Lands Subsoil. Benton Co.	Prairie Subsoil. Monroe Co.	H'y Flatwoods Soil. Pontotoc Co.	Red Hills Subsoil. Attala Co.	Hog-wallow Subsoil. Jasper Co.	Buckshot Soil. Issaquena Co.	Loess. Claiborne Co.	Tallahatchie All. Soil. Panola Co.	Frontland Subsoil. Sunflower Co.	Dogw. Ridge Soil. Coahoma Co.	Southwest Pass. Plaquemine Par.	Southwest Mud-lump. Plaquemine Par. La.	Sacramento. Sacramento Co.	Gila. San Diego Co.
Grit........	1-3			6.94	2.90	0.36	0.36		0.23	2.10	0.33	1.97	0.83	0.09	0.24	0.09						
Sand.....	.5-1			17.65	6.96	2.98	0.83				0.35		1.19	0.05								
	.50	64	0.06	18.81	2.81	6.62	6.21	0.79	1.47	0.62		0.72	1.96		0.37	0.04	0.32	0.15	0.18	0.10		.13
	.30	32		10.16	4.41	7.75	3.38		2.33			2.32	1.64	0.36	0.61	0.05						.15
	.16	16		2.66	3.13	3.01	3.85		1.17			2.09	0.88		0.93	0.21	2.79		0.47	5.02		.11
	.12	8	0.08	1.66	2.02	1.59	1.49	0.18	0.78	0.20	0.23	0.70	0.26	0.31	1.65	1.30	2.41	3.75	7.03	3.68	.32	.75
Silt.......	.072	4	0.02	1.02	2.23	1.19	0.64	0.78	0.76	1.26	0.18	1.29	0.19	0.27	1.95	2.68	16.90	21.46	12.38	5.34	3.16	2.51
	.047	2	0.04	0.88	5.06	3.56	2.63	3.56	9.79	2.92	1.61	1.80	2.49	1.56	14.25	9.38	19.97	21.83	13.27	10.09	10.27	8.32
	.036	1	0.08	1.96	9.67	6.50	5.40	13.12	7.26	7.36	2.66	3.60	3.67	2.23	16.20	9.88	13.90	14.01	15.87	5.58	13.67	12.64
	.025	0.5	0.08	7.89	14.18	13.97	7.77	16.64	13.14	8.81	9.13	2.73	5.39	3.68	20.08	20.37	4.27	9.93	8.25	9.54	13.11	11.28
	.016	0.25	2.00	8.40	22.03	14.20	16.65	27.28	15.07	7.85	26.64	13.30	10.31	8.97	5.59	19.79	1.89	9.58	7.26	8.01	43.61	31.79
	.010	<0.25	21.15	15.53	15.62	29.36	37.75	18.87	26.50	35.22	32.35	25.33	24.18	38.19	33.38	25.30	30.08	8.65	19.67	34.46		
Clay........	?	<0.0023	74.65	8.63	7.86	4.58	10.70	17.23	19.19	33.16	25.48	40.25	47.03	44.30	2.51	9.64	5.51	10.35	12.20	18.18	12.06	23.97
			98.16	99.28	98.68	95.67	97.77	98.35	97.65	99.50	97.87	96.11	100.00	100.01	97.74	98.73	98.04	99.72	96.58	100.00	96.20	91.71
Hygroscopic Moisture (+7=to+21°C)........			9.09	1.80	3.36	2.48	7.69	8.79	7.24	11.35	9.33	18.60	14.48	14.31	4.18	6.12	5.68	3.95			9.18	9.26
Ferric Oxid.............			0.13	1.10	(1.45)	1.25	4.45	2.53	5.11	5.42	(5.90)	10.50	4.00	(5.82)	3.27	2.58	2.31	2.69				

Number of soil grains per gram.—It is of some interest to consider the number of grains of different sizes that may be contained in, *e. g.*, a gram of soil. If for this purpose we assume all the soil grains to be spherical, we shall obtain the minimum figures, for most other shapes will pack more closely. King (Physics of Agriculture, p. 117) calculates such figures for different grain-sizes, assuming the density to be that of quartz (2.65), with the result that while with a diameter of one millimeter (1-25 inch) the number of grains would be 720, and with one-tenth of a mm. 720,000; if made of the finest particles only, viz., one thousandth of a mm., the number would be 720,000 billions. Probably few of the clayey soils we ordinarily deal with are of this order; it is doubtless approached in certain fine plastic clays.

Surface afforded by various grain-sizes.—The amount of *surface* afforded by a similar amount of soil must naturally be considered in this connection, since upon it depends not only the amount of moisture which the soil may hold in the form of superficial films, but also the extent of surface upon which the weathering agencies as well as the root hairs of plants may act. Quoting again from King's work, we find on the same premises given above for the *number* of grains, that their *surface* would in the case of grains of one mm. diameter be eleven square feet per pound (about half a pint) of material; while in the case of the finest grade we should have 110,538 square feet, or more than two and a half acres.

From actual experiments made with the flow of air through various soils, King calculates that while in ordinary loam soils the total surface is about an acre per cubic foot, in fine clay soils it rises to as much as four acres. If we imagine this large surface to be covered with even a very thin film of water, it is readily seen how large an amount may be present in a cubic foot of moist soil.

E. A. Mitscherlich (Bodenkunds für Land-und-Forstwirthe; Berlin, 1905) attributes to the surface offered by the soil particles supreme importance in determining the productiveness of soils. According to him the internal soil-surface determines directly the ease with which roots can penetrate the soil; and he proposes the determination of this factor by means of the heat produced in wetting the soil ("Benetzungswärme"), measured in a calorimeter, as a substitute for all methods of physical soil analysis, which are vitiated by the varying shapes and densities of the particles; while his method gives directly the actual surface. To the consumption of energy required by difficult penetration he attributes most of the differences in production, and hence refers to the internal soil-surface as governing nearly all the other physical factors. The introduction of many arbitrary assumptions, and the failure to show that the admitted inaccuracy of the ordinary mechanical soil analyses are of any practical importance, greatly detract from the cogency of the rigorous mathematical discussion carried through his work by Mitscherlich.

Influence of the several grain-sizes on soil texture.—Undoubtedly the most potent of all the sediments appearing in the above table in influencing soil texture, is the "clay." That the materials included under this empirical designation may vary considerably in different soils, has already been sufficiently insisted on; and it is doubtful that in the present imperfect state of our knowledge of the functions of the several physical grain-sizes, we would be much wiser were we to go to the extreme advocated by Williams (Forsch. Agr. Phys., vol. 18, p. 225, ff), of determining with precision the actual amount of such extremely fine clay particles as cease altogether to obey the law of gravity when once suspended in water. It is at least doubtful that the essential property of adhesive plasticity belongs only to these, for this property doubtless increases gradually as the size diminishes, although unquestionably not a mere function of the latter, since it belongs only to the hydrated silicate of alumina.

Ferric Hydrate.—Probably the body which most commonly modifies materially the adhesive and contractile properties of the clay substance, is ferric hydrate; the more as on account of its high density it tends to exaggerate materially, in many cases, the apparent content of true clay, and the estimate of the soil's plasticity based upon it. A good example in point is the case of soil No. 246 (Miss.) of the above table. This is a heavy clay soil, yet not excessively adhesive; scarcely as much so as No. 230 (Miss.), the heavy gray "flatwoods" soil, and not nearly as "sticky" when wet as No. 173 (Miss.), the prairie subsoil, although containing apparently 15 % more clay than the former, and 7 % more than the latter. But No. 246 is a highly ferruginous clay, in which the ferric hydrate is in a very finely divided condition, and materially influences the physical qualities of the clay substance. Were it all accumulated in the "clay," it would diminish the percentage of true clay by 11.75 %, reducing the clay-percentage to 28.5 % which accords more nearly with the soil's only moderate adhesiveness, and not excessively heavy tillage.

But it must be remembered that the iron oxid shown in the analysis is not nearly always in this finely diffused condition. Frequently it incrusts the sand grains; quite commonly it forms small concretions of limonite, which themselves act as sand grains; and again, it may be present in the form of "black sand" or magnetic oxid, as is commonly the case in California and on the Pacific slope generally. To take this point properly into account, therefore, it would be necessary to determine the amount of ferric hydrate actually present in the "clay" as separated by subsidence of the granular constituents.

Other substances.— This circumstance as well as the inevitable presence of other modifying substances, clearly shows the desirability of being enabled to examine the physical properties of this "clay" directly, by collecting its entire amount as obtained in analysis, instead of merely determining it by weighing fractional portions. When this is done the analysis is much more valuable as indicating the true tilling qualities of the land. The increase of bulk suffered by this substance after wetting, is a very fair index of its content of true clay, and is preferable to the chemical analysis proposed by some investigators. For it is quite impossible to distinguish the silica and alumina derived from the kaolinitic substance proper, from that which is due to the decomposition of zeolites.

It *is* possible, however, to determine the possible *maximum* of the kaolinite ingredient by taking into consideration the quantitative ratio according to which silica and alumina combine to form it, viz., approximately 46% of the former to 40 of the latter, the rest being water. By using this calculation we can often demonstrate clearly the presence in the "clay" of considerable amounts (up to 33%) of *aluminic hydrate;* since no zeolitic mass can contain as much alumina as does kaolinite, Whether the aluminic hydrate be in the form of gibbsite, bauxite, disapore,[1] or in the gelatinous state, the nature of the soils containing it proves that it is totally destitute of plasticity and adhesiveness; and this consideration will often serve to explain the fact that soils showing in their chemical analysis high percentages of alumina, nevertheless show quite low degrees of plasticity, adhesiveness and water absorption. What part it may take in modifying the physical properties of the soil we can thus far only conjecture.

Influence of the granular sediments upon the tilling qualities of Soils.—Considering the granular sediments by themselves, in the absence of clay, it may be stated in a general way that while in a moist condition they flocculate sufficiently to produce a fair tilth, they will nevertheless on drying collapse into a close arrangement resulting from the single-grain structure. The form of the grains being angular instead of rounded, they are apt to form a very closely packed mass far from suitable to vegetable growth; as will be seen by an example taken from one of the culture stations of the University of California, from a piece of land which on the surface would be called a very sandy loam, but after we descend increases in its content of fine grains until at a depth varying from eighteen inches to three feet we find what appears to be a hardpan, which is equally impervious to roots and water and causes the water to stagnate to such an extent that after heavy rains the land becomes so boggy as to render plowing almost impossible without endangering the team. A close examination of this hardpan shows that, unlike others, it is devoid of any cement, and when taken out can be readily crushed between the fingers, and softens in water, but does not become plastic. Its imperviousness is therefore due solely to the close packing of the sand grains, for it contains practically no plastic clay, and under the microscope the grains are seen to be angular-wedge-shaped and composed of the remnants of granite. The physical analysis shows the following result:

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[1] **Bauxite is not only the most abundant of the three hydrates of alumina known to occur naturally, but also stands nearly midway between the two others in its water content, viz., a little over 25°/₀; that of diaspore being nearly 15°/₀, gibbsite about 35°/₀.**

MECHANICAL ANALYSIS OF HARDPAN.

Designation.	Diameter.	Percentage.
Sand................	.50 mm.	10.93
	.30 "	21.23
	.16 "	7.58
	.12 "	7.27
Silt................	.072 "	9.63
	.047 "	12.00
	.036 "	7.19
	.025 "	1.25
	.016 "	14.20
"Clay"...............	?	8.64

It is doubtful whether this condition of things can be remedied by the usual measure of breaking up the hardpan either by hand or by means of giant-powder blasting. Experience seems to show that the effect is only temporary, and that in the course of time, by the action of the percolating waters, the particles settle back into their original impervious condition. It is just possible, however, that if once penetrated by roots, the intervention of these would permanently destroy the close structure, so as to make this a fair subsoil for the growth of trees and other plants. The writer is not aware that this kind of purely physical hardpan without cement has ever been observed elsewhere.

This physical condition is doubtless responsible for two other phenomena, viz., the "putty soils," and also certain difficulties experienced in irrigation.

"Putty Soils" is the name popularly given in the Cotton States, and probably elsewhere, to soils usually occurring in low ground and also known as "cray-fishy." They consist of very uniform, powdery sediment, with little or no coarse sand and still less of clay to render them coherent. When wet these soils behave precisely as would glazier's putty, adhering to the surface of even the best-polished plowshare, so that no furrow-slice can be turned and the plow is soon dragged out of the ground. At a very closely limited condition of moisture such lands may plow fairly well; but when this limit is passed in the least (as sometimes happens in the course of a single day), it turns up only hard clods, which in a few hours of sunshine become so hard that no instrument of tillage short of a sledge-

hammer will make any impression upon them. The physical analysis of these usually gray soils shows that they contain only a trifling amount of clay; perhaps 1 or 2%, playing the part of linseed oil in making putty out of whiting. Even the addition of lime does not help such soils much, because there is little or no clay to flocculate. They are, as a matter of fact, among the most refractory lands the farmer has to deal with. A soil showing similar behavior, though not quite as extreme as in the case of the Gulf or Cotton States' soils in question, occurs at the culture substation at Paso Robles, California, and is probably closely correlated to the physical hardpan referred to above. The physical analysis of this soil yielded the following result:

MECHANICAL ANALYSIS OF SOIL.

Designation.	Diameter.	Percentage.
Sand	.50 mm.	14.24
	.30 "	15.17
	.16 "	8.88
	.12 "	5.60
Silt	.072 "	6.75
	.047 "	8.35
	.036 "	8.55
	.025 "	6.03
	.016 "	17.77
"Clay"	?	7.50

It would seem the best and almost only remedy to be applied to such soils as these is the introduction of vegetable matter or green-manuring, by which their texture is loosened: for the hauling of mere clay upon the land would hardly accomplish the purpose intended, within the limits of farm economy.

Dust Soils, which during the dry season are even in their natural condition so loose as to rise in clouds and render travel very uncomfortable, are not uncommon in arid countries, *e. g.*, in Washington and adjacent parts of Oregon, on the uplands bordering the Columbia, Yakima and Snake rivers. The physical analyses of three of such soils, given in the table below, will convey some idea of their peculiarities in this respect.

PHYSICAL ANALYSIS OF DUST SOILS.

	Hydr. Value.	Diameter.	No 17.	No. 37.	No. 79.
Clay.	<.0023. mm.	<.10—?	.93	3.59	1.27
Silt.	<.25 mm.	.010	30.93	13.06	32.29
	.25 to .5	.016	3.20	5.82	12.75
	.5 to 2.0	.025—.047	7.18	27.37	37.51
	2.0 to 8.0	.047.—.120	21.88	43.78	10.92
Sand.	8.0 to 64.0	.12— .50	32.39	49.57	3.97
Total.	. . . .	. . . .	96.57	98.18	98.72

Slow penetration of Water.—Soils of this class are wetted with extreme slowness by irrigation water; so that when first taken under cultivation it sometimes takes twenty-four hours to soak the land for twelve inches in each direction. Irrigation furrows must be placed very close together and in large numbers, in order to ensure the wetting of the soil so that the crop shall not suffer from lack of moisture at a distance of two or not more than three feet. Where the irrigation furrows are drawn farther apart a fine stand of grain may be seen within eighteen inches of the same, while farther away the crops may be dying from lack of moisture. This difficulty is by no means infrequent in the arid region, and is difficult to overcome except by frequent and thorough tillage, which gradually increases the rapidity of water-penetration; as has been shown in the soils of the alluvial prairies of the Yakima country in the State of Washington. It is necessary, however, to take care that they shall always contain an adequate amount of humus or vegetable matter, in order to prevent re-consolidation by the burning-out of the humus during the warm, rainless season.

There is an unmistakable resemblance between these dust soils of the Northwest and the "putty" soils mentioned above; both showing a very low percentage of clay with a relatively large amount of the finest sediments, with a sudden downward break of the curve before the coarser grain-sizes are reached. It would seem as though the absence of these intermediate grains favors the close packing of the fine sediments in the interstices of the coarse ones, thus bringing about the imperviousness, which is the chief obstacle to their cultivation.

Effects of coarse Sand.—Coarse sand intermingled with heavy clay soils has but little effect in improving the tilling qualities, unless carried to such excess as renders it financially impracticable. In actual practice it is frequently possible to improve such soils by properly distributing upon them the washings of the adjacent hills, which will always carry sands of many grades; and when it is intended to improve garden land by hauling sand it is important to choose the latter so as to complement the deficient grain-sizes of the soil. The sand of wind drifts or dunes is generally well adapted to such improvement, being, as Udden[1] has shown, of a fairly definite composition of sufficiently wide range of grain-sizes for the purpose.

The effects of humus in modifying soil texture are discussed farther on.

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[1] The Mechanical Composition of Wind Deposits, Bull. No. 1, Augustana Library Publications; 1898.

CHAPTER VII.

THE DENSITY AND VOLUME-WEIGHT OF SOILS.

Aside from the humus-substances the specific gravity of the common soil constituents, taken individually, do not vary widely; kaolinite being the lightest (2.60), feldspar next (2.62); then quartz (2.65), calcite (2.72). Mica and hornblende range (according to their iron contents) from 2.72 to over 3.0. The average specific gravity of soils of ordinary humus content only will thus range between 2.55 and 2.75; sandy soils approaching very closely to that of quartz alone.

Volume-Weight.—The specific gravity of the soil is, however, of little practical consequence compared with the "*volume-weight,*" *i. e.,* the weight of the natural soil as compared with an equal bulk of water. A cubic foot of water weighs 62½ pounds; a similar volume of soil usually weighs more, but in the case of peaty lands may actually (when dry) weigh less. The extreme range is from 110 pounds for calcareous, and somewhat less for siliceous sand, to as little as 30 to 50 pounds in the case of peaty and swamp soils. It may be conveniently remembered that while average arable loams range from 80 to about 95 pounds per cubic foot, "heavy" clay soils range from 75 pounds down to 69, observed by the writer in the case of certain alluvial soils, poor in humus,[1] of the Sacramento river, California. Manured garden soils, and the mold surface soil of deciduous forests, generally contain so much humus as to depress their weight considerably, varying according to their state of tilth from 66 to 70 pounds per cubic foot.

Weight per acre-foot.—As for practical purposes and calculations it is often desirable to know approximately the weight in pounds of an acre (43,560 square feet) one foot deep, it is convenient to remember that in the case of sandy land, this weight (per "acre-foot") may be assumed at four millions of pounds; for loams, at 3½ millions; for clay lands, 3¼

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[1] This remarkable soil seems to have been derived from the finest "slickens" of the hydraulic gold mines.

millions; for humus or garden land and woods earth, about 3 millions of pounds; for reedy swamp and peaty lands, 2 to 2½ millions.

The loose tilth and humus-content of the surface soil will in general cause it to weigh less, bulk for bulk, than the underlying subsoil, even when the latter is more clayey; moreover, the continuous pressure from above will tend to consolidate the subsoil and substrata. Warington (Phys. Properties of Soils, pp. 46, 47) gives interesting data on this point from the Rothamstead fields, as follows:

Old pasture, first nine inches	71.3	pounds per cub. ft.
Same, fourth do. do.	102.3	" " " "
Arable land, first do. do.	89.4	" " " "
Same, fourth do. do.	101.4	" " " "

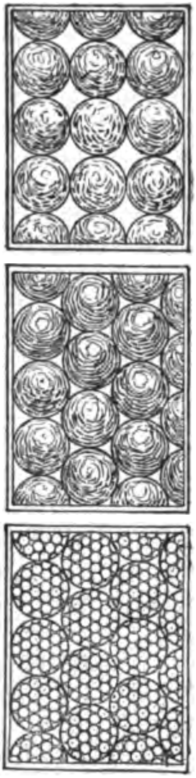

FIG. 10.—Various possible arrangements of soil particles.

The influence of humus and unhumified organic matter, as well as of tillage, in diminishing the volume-weight of soils is here strikingly shown.

Air-space in Natural Soils.—The difference between the specific gravity as usually determined, and the volume-weight of soils, is of course caused by the large amount of air contained in them when dry, but which in wetting them is partially or wholly replaced by water.

Theoretically, assuming all soil grains to be globular, and packed as closely as possible (in oblique order), the space not filled by them would be the same for all sizes, whether that of marbles, or so minute as to be hardly felt between the fingers; and would be 25.95 per cent of the soil volume.[1] If the same globular particles were packed as loosely as possible, *i. e.*, in square instead of oblique order (see figures 10 and 11), the vacant space would be 47.64 per cent. If however we imagine each sphere to be itself composed of a number of smaller ones, the empty space will obviously be greatly increased, to an ex-

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[1] King, Physics of Agriculture, p. 116, ff.

tent proportionate to the diminution of solid mass thus brought about. The pore-space might in that case, with the oblique arrangement of the globules as shown in Fig. 10, be as high as 74.05 per cent. But since the soil particles may be of all shapes and sizes within the same soil, and usually fit much more closely than would globular grains, the empty space rarely approaches (only in certain alluvial soils and in loose mulches) to the figure last named. In sandy soils it may fall as low as 20%, and in coarse gravelly soils even as low as 10%. Most cultivated soils range between 35 and 50% of empty space.

Effects of Tillage.—That these figures can be only approximations is obvious from the consideration that one and the same soil will vary materially in its volume-weight according to its temporary condition of greater or less compactness. After land has been beaten by winter rains, its volume-weight will be found to have materially increased from the well-tilled condition brought about by thorough cultivation. This difference is strikingly seen when, in plowing, the height of the ground on the land side is compared with that of the turned furrow-slice in well conditioned loamy land. This loose condition is called *tilth,* and it results from the formation of relatively large, complex crumbs[1] or floccules, between which there are large air spaces that were wholly absent in the untilled land; the floccules themselves being also more loosely aggregated than was the case before tillage.

Crumb or Flocculated structure.—Figure 11 illustrates the difference between the unplowed land, consolidated especially on the surface by winter rains, and in its upper portion consisting largely of single grains; while the plowed land, toward which the furrow-slices have been turned, is greatly increased in height and volume and consists almost wholly of variously-shaped and-sized aggregates or floccules, loosely piled upon one another and separated by large interspaces. The increase

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[1] The word crumbs, which is generally understood as meaning a relatively large, loose aggregate, seems preferable to the word kernels, suggested for the same by King (Physics of the Soil, p. 110). Kernels are understood to be bodies rather more solid than the surrounding mass, and do not convey the idea of loose aggregates. The word "Krümelstructur" (crumb-structure), adopted by Wollny for this phenomenon, has both fitness and priority in its favor.

in volume from consolidated clay to crumb-structure is given by Wollny (Forsch., vol. 20, p. 13, 1897) at 41.9%, to powder as 33%. On moistening dry clay increased 36.9%, quartz powder 8.01%. When land is plowed in the proper moisture-condition the crumbs of floccules are held together by the surface tension of the capillary films (menisci) of water at the points of contact. In the case of sands, the crumbs will collapse into single grains whenever the water-films evaporate, unless some cementing substance was dissolved or suspended in the water. (See figure 12). Lime carbonate is one of the substances most commonly found permanently cementing the floccules; hence the ready tillage of most calcareous soils, and especially the loose texture of the "loess" of the western United States, and of Europe and Asia. In these deposits we find sandy and silt aggregates or concretions ranging from ten or more inches in length (loess puppets) to microscopic size, held together by lime carbonate, but collapsing into silt and sand when the material is treated with acid so as to dissolve the cement. The rough surfaces of these aggregates, gripping into each other, explain the stability of the steep loess cliffs in the United States, as well as in northeastern China, as observed by Von Richthofen and Pumpelly.

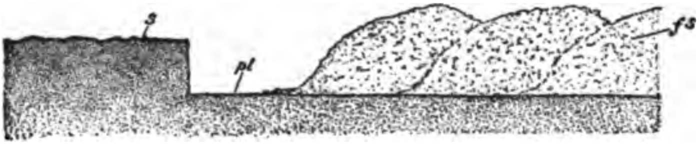

FIG. 11.—Land before and after plowing. The compactness of the soil is indicated by the density of dotting. Before plowing there is a compact surface crust (s), below which the soil becomes less and less compact as we go deeper. After plowing we find the soil (fs, furrow-slice) converted into a loose mass of crumbs (floccules), with increase of bulk. Compacted plow-sole at pl

FIG. 12.—A soil-crumb, magnified to show the particles of which it is composed. The particles are held together by the water-menisci, just as are the hairs of a brush when wetted. The white spaces between the particles represent air.

Clay is most frequently the substance which imparts at least temporary stability to the crumbs and crumb-structure; this is one of its most important functions in soils, as it serves to *maintain* tilth once imparted by cultivation, even after the land dries out. Beating rains, and cultivation while too wet, will in this case of course destroy the crumbs and the loose tilth.

Other substances which greatly aid the maintenance of tilth are the several humates (of lime, magnesia, iron), which when fresh are colloidal (jelly-like) like clay itself, but unlike the latter, when once dried do not resume their plastic form by wetting (Schloesing). The crumbs thus formed are therefore quite permanent and contribute to the looseness of soils rich in humus. One part of lime humate is said by Schloesing to be equal in cementing power to eleven parts of clay.

Silica, silicates and ferric hydrate are sometimes found cementing soil crumbs, wholly or in part.

The importance of the ready penetration of air, water and roots thus rendered possible is obvious; and the question arises how it happens that wild plants are able to do without tillage.

How Nature Tills.—When we examine the undisturbed soil of woods or prairie in the humid region, we will as a rule find the natural surface soil in a very good condition of tilth; the obvious cause being the presence in it of an abundant network of surface roots and rootlets of grasses and herbs, which in connection with the fallen foliage prevent the beating and compacting of the soil surface; which can be seen to happen before the observer's eyes whenever a heavy rain falls on a bare land surface, however well tilled.

Crusting of Soils.—In some soils, especially of the Gulf States, the beating of rain followed by warm sunshine so effectually compacts the surface that in the case of taprooted plants like cotton, it becomes necessary to cultivate after each rain, so as to break the crust that would otherwise not only prevent the proper circulation of air, but would also serve to waste the moisture of the land. The same land in the wild condition suffered no such change, being protected by the native vegetation, and by fallen leaves. (See chapt. 8).

Soils of the arid region.—In the regions of deficient rainfall the conditions are modified in several respects. Grass sward rarely exists, nearly all grasses assuming the habit growing in tufts or bunches some distance (a foot or two) apart;

hence the name of "bunch grass" commonly used, which however means not any one definite kind of grass, but serves to distinguish the grasses of the uplands from those of the moist lowlands, where true sward may be found. Between these bunches of grass the soil is fully exposed, and being free from roots and leaf-covering is compacted, *unless its nature is such that the usually gentle rains do not produce a serious crusting of the surface.*

That such is actually the predominant nature of the soils formed under arid influences has already been stated; and thus the hard-baked soil-surface so often seen in the Eastern United States in unplowed bare land, or during the prevalence of a drought, is rarely seen in the arid region. The clay lands that do exist are usually sufficiently calcareous to possess the property of "slaking" into crumbs whenever wetted after drying. But where this is not the case, the stony hardness brought about by the long dry and warm season is long in being removed by the winter rains.

Charges of soil-volume on wetting and drying.—The behavior of colloidal clay in the above respects has already been described above (see chapt. 4, page 59). It is obvious that whenever soils contain a large proportion of such clay, their behavior on wetting and drying will approximate to those of the pure clay. This is exemplified in the heavy clay, or so-called "prairie soils" of the United States, which when thoroughly wetted in spring will, during a dry summer, form wide, gaping cracks. These in the long summers of the arid region may extend to the depth of several feet, with a width of as much as three and more inches at the surface of the ground. This, of course, contributes greatly to the drying-out of the soil to the same depth, and results as well in the mechanical tearing of the root-system of growing plants; sometimes causing the total destruction of vegetation. In some clay soils it happens that after a rain or irrigation, the shrinkage occurring upon the advent of warm sunshine will cause the surface crust to so contract around the stem, *e. g.*, of grain, as to constrict and *injure the bark,* causing serious injury to the crop. In soils of this character very *thorough tillage in preparing for a crop,* and the maintenance of *a loose surface during its growth, are of course extremely essential.*

In the arid region it will frequently happen that such soils when not tilled to a sufficient depth, will during the later part of the summer so shrink and crack beneath the shallow-tilled surface layer that the latter will bodily fall into the cracks, exposing the roots to all the deleterious influences of mechanical lesion and drying-out. It is thus obvious that the cultivation of such soils should not be undertaken at all by those not naturally able and willing to bestow upon them, to the fullest extent, the deep and thorough tillage which is absolutely essential in the utilization of their usually high productive power.

Extent of Shrinkage.—The extent of this shrinkage in drying, and subsequent expansion in wetting, have been measured by the writer by the use of the sieve cylinder described below (chapt. 11, p. 209), as serving for the determination of the water capacity of soils. When a soil of the kind above referred to is placed in the sieve cylinder in the tilled (flocculated) condition, then allowed to absorb its maximum of water and then dried at 100 degrees C., the contraction in drying can be very strikingly seen, and its amount measured by filling up the empty space with mercury; then measuring the latter after expelling the surplus by means of a ground glass plate laid on top. The contraction of several heavy clay soils, thus measured, has been found by the writer to range from 28 to as much as 40 per cent. of the original bulk.[1] The soil thus contracted, when again wetted, does not return altogether to its original bulk, but remains in a more or less compacted condition, like that of a soil which has been rained upon.

The expansion and contraction of a heavy clay soil on wetting and drying are well illustrated in the figure below, in which the soils are shown in the shallow cylinder which serves for the determination of water-holding power (see chapt. 11, p. 209). The middle figure shows in profile the expansion of a dry, pulverized "black adobe," struck level, when allowed to absorb its maximum of water; it rises above the rim of the sieve-box to nearly the half height of the latter. The outside figure to the right shows the same soil after drying; that to the left, a red clay soil similarly treated. It is easily seen that these variations in volume may bring about very marked results in

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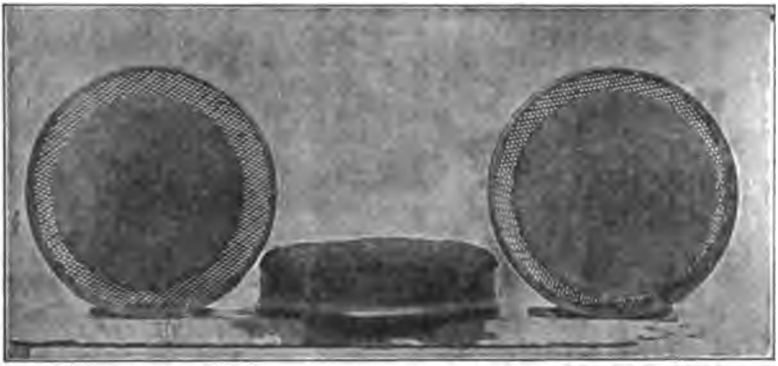
[1] Wollny (Forsch. Vol. 20, p. 13 ff, 1897) records similarly high shrinkages in his experiments.

the fields; the surface of which, apart from the cracks usually formed, may be several inches lower in the dry season than during wet weather.



Red Clay Soil. Black "Adobe" Clay Soil.

Fig. 13.—Expansion on Wetting and Contraction on Drying of heavy clay soils.

Contraction on Wetting.—In the case of alkali soils containing much carbonate of soda, a very notable *contraction* occurs in *wetting* the loose, dry soil. The cause is here obviously the collapse of the crumbs, formed in dry tillage or crushing, into single grains, closely packed. The same result is observed in the naturally depressed "alkali spots" (see chapt. 22).

"Hog-wallows."—In the *field* the wetting of cracked clay soils produces some very curious effects. The effect of the first light rains usually is to crumble off the edges or angles near the surface, the materials thus loosened falling into the lower portion of the cracks. This is repeated at each successive shower followed by sunshine, the crevices thus becoming partly filled with surface soil. When, subsequently, the heavier and more continuous rains wet the land fully, also causing the consolidated mass in the crevices to expand, the latter cannot close on account of the surplus material having fallen into them; the result being that the intermediate portions of the soil are compelled to bulge upward, sometimes for six or more inches, creating a very uneven, humpy surface, well-known in the southwestern United States as "hog-wallows,"[1]

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[1] A totally different kind of "hog-wallows," occurring in California and the arid region generally, have been described in a previous chapter under the head of Aeolian soils (See chapt. 1, p. 9).

Such a surface is always therefore an indication of an *extremely heavy soil, difficult to cultivate;* yet embracing some of the most highly and permanently productive lands known in the United States, and in India, where the "regur" lands of the Deccan are of this character; they have been cultivated without fertilization for thousands of years. The subjoined physical analyses of lands of such extreme character as to be almost uncultivatable will serve to exemplify their physical composition.

PHYSICAL ANALYSES OF HEAVIEST CLAY SOILS.

	No 242 Miss. Hog-wallows soil. Jasper Co. Mississippi.	No. 643 Cal. Black Adobe. Contra Costa Co. California.
Weight of gravel over 1.2 mm. diameter	.83	
" " between 1.2 and 1 mm.		
" " between 1 and 0.6 mm.	1.19	
Fine earth	97.98	100.00
	100.00	100.00

FINE EARTH.

	Hydr. Value.	Diameter.	No 242 Miss.	No. 643 Cal.
Clay	<.0023 mm	?	48.00	45.96
Silt	<0.25 mm	.010	35.18	37.64
	0.25 mm	.016		
	0.5 mm	.025	5.50	2.74
	1.0 mm	.036	3.74	3.31
	2.0 mm	.047	2.54	2.95
	4.0 mm	.072	.20	2.39
Sand	8.0 mm	.120	.27	1.68
	16.0 mm	.160	.90	.79
	32.0 mm	.30	1.67	2.36
	64.0 mm	.50	2.00	....
			100.00	100.00

It will be noted that in both these extremely heavy soils the sum of the clay and finest sediments is a little over 83%.

It should be stated that both these soils after being thoroughly wetted become so adhesive that it is almost impossible to travel over the tracts occupied by them, and that they are practically almost untillable, being too adhesive when wet; yet if allowed to dry to a certain extent (varying within very narrow limits) they turn up by the plow in large clods, which after a few hours of sunshine become of stony hardness and will resist all efforts at pulverization or the production of tilth.[1]

Calcareous Clay Soils crumble on drying.—The heavy clay soils of some of the calcareous prairies of the Southwest, instead of contracting into a stony mass on drying, on the contrary resolve into a mass of crumbs, thus producing excellent tilth. This occurs even though the land may have been plowed when wet, and of course is a great advantage. The most striking exemplification of this peculiarity occurs in the heavy but profusely fertile "buckshot" clay lands of the Yazoo bottom, in Mississippi, where it is usual to plant corn and sweet potatoes in the semi-fluid mud left after an overflow, after turning a shallow fürrow, then covering by turning another. To the onlooker it seems impossible that such plantings could be successful; but within a short time the muddy surface becomes a bed of crumbs ("buckshot"), forming a seedbed not readily excelled by any made by artificial means. Hence, largely, the almost invariable success of crops in the Yazoo region.

Port Hudson Bluff.—The same clay produces a most unpleasant result at the foot of the Port Hudson bluff, where it crops out some feet above low water. When after a freshet the water level falls below this stratum, on drying the clay disintegrates into crumbs just as does the Yazoo buckshot soil; with the result that at the next rise, the loose mass subsides into the river as a flood of mud. Thus the foot of the bluff is being constantly undermined, and the falling of the bluff scarp has obliged the town above to recede many hundreds of feet from its original historic site.

The exact proportions of lime carbonate necessary to produce this phenomenon, and its necessary relations to clay substance and other physical soil ingredients, yet remain to be investigated.[2]

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[1] In driving a light carriage over the land represented by No. 643 above, after a light rain, the wheels gathered up so much soil within a hundred yards as to render it necessary to stop and chop it off the tires by means of a hatchet. This is a common experience in the black prairie lands of Texas.

[2] Schübler (Grandsätze d.Agrikulturchemie, 1838) ascribes the crumbling of calcareous clay soils to the difference in the contraction of calcareous sand and the clay substance. But it is doubtless more directly connected with the flocculation of the latter by lime.

Loamy and Sandy Soils.—It is largely the *absence* of these extreme changes of volume that renders the cultivation of loamy or even sandy lands so much more easy, and the success of crops so much more safe, than is the case in clay soils. Whenever the content of colloidal clay diminishes below 15%, the shrinkage in drying from the wet condition becomes so slight as to cause no inconvenience; while in sandy soils properly speaking, no perceptible change in volume occurs.

Peaty soils, however, and all those containing a relatively large amount of humus, are also liable to visible shrinkage when passing from the wet to the dry condition. But on account of their looseness and porosity such shrinkage does not usually result in the formation of cracks or rupture of the roots, as is the case in heavy clay lands. The entire mass of the soil then shrinks downwards, but rarely forms cracks on the surface. Hence the introduction of humus into " heavy " soils is among the best means of improving their tilling qualities.

Formation of Surface Crusts.—Some soils, especially those of a clay-loam character, are very liable to the formation of hard surface crusts from the beating of rains, and from surface irrigation; owing, doubtless, to the ready deflocculation of their clay substance. It is not easy to define the precise physical composition conducive to this crust formation; but the subjoined physical analyses show examples of soils in which this tendency is very prominent and is frequently annoying, in that when they occur in the regions of frequent summer rains, it becomes necessary after each one to till the surface in hoed crops (*e. g.*, in cotton-fields) in order to prevent the injurious effects of such consolidation of the surface. It may, of course, be prevented by mulching, or on the large scale by green-manuring, to such extent as to prevent contraction.

The subjoined physical analyses of two soils from the Brown-Loam region of Northern Mississippi (see chap. 24), shows the composition of lands excellent in every respect other than the tendency to crust after each rain:

PHYSICAL ANALYSES OF CRUST-FORMING SOILS.

	Diameter.	Hydr. Value.	No. 219.	No. 197.
Coarse materials........	1—3 mm.		.23	
	.5—1 "			
	.50	64 mm.	1.47	
Sand..	.30	32 "	2.33	.79
	.16	16 "	1.17	
	.12	8 "	.78	.18
	.072	4 "	.76	.78
	.047	2 "	9.79	3.56
Silt....	.036	1 "	7.20	13.12
	.025	.50	13.11	16.64
	.016	.25	15.07	27.28
	.010	<.25	26.36	18.87
Clay.......	?	<.0023	19.10	17.23

These soils agree in having a sufficient amount of clay (17 to 19 %) to characterize them as clayey loams, associated with a very large proportion of the grain-sizes of less than .025 mm., or .5 mm. hydraulic value. A higher proportion of clay, even though associated with a similarly high or even larger proportion of these fine sediments, seems to prevent crusting, probably because the swelling of the clayey ingredient on wetting and its extravagant contraction in drying breaks up the continuity of the surface. The heaviest clay soils, such as those shown on a preceding page, neither crust nor crumble on drying after wetting, but contract into lumps of stony hardness, *as a whole.*

The burning-out of the humus from well-tilled surface soils during the extended heat and dryness of rainless summers, brings about such a contraction or packing of the surface soil of orchards in California as to greatly reduce their productiveness, and to render necessary diligent green-manuring as the only practical remedy. In many cases, liming of the surface also serves well to prevent this injurious effect, which to some extent of course follows surface irrigation as well as rains.

In most soils, repeated alternate wetting and drying *in place* produces a loose, flocculated texture, so long as no deflocculation is brought about by mechanical causes, such as beating rains or running water.

Effects of Frost on the Soil.—The expansion suffered by water in freezing necessarily tends to separate the soil particles previously held together by the surface tension of the capillary water, or otherwise flocculated or cemented. Freezing of the soil is therefore of material assistance in *disintegrating* cloddy, ill-conditioned soils, leaving them in loose, crumbly condition after the ice has melted and the surplus water drained off; so as to materially facilitate tillage and root penetration. When, however, soils thus circumstanced are tilled or trodden while too wet, they quickly become puddled, being practically reduced to single-grain structure. (See this chapt. p. 110). Hence the injury caused by allowing cattle to range in winter on cultivated land subject to freezing and thawing, which it sometimes takes years to correct.

A disagreeable effect often produced by the freezing and thawing of wet lands is the "heaving-cut" of grain, resulting from the upward expansion of the surface soil in freezing, that may readily rupture the roots; while on thawing, the soil surrounding the upheaved stool is apt to settle down, especially in case of a rain, leaving the stool and roots exposed either to drying or freezing, as the case may be. Hence the desire of grain farmers in northern climates, for a sufficient covering of snow to protect the fall-sown grain, rather than an "open winter," during which the grain is exposed to alternate freezes and thaws, or extreme cold.

In certain soils, notably in those liable to crusting (p. 117), instead of heaving the soil, the water in freezing emerges bodily from small cracks, in foliated or wire-like forms ("ice-flowers") resembling those of native silver, and formed substantially in the same way, by a kind of "wire-drawing" process, aided by crystallization.

Small ice-crystals formed on the surface of small crevices filled with water cause others to be formed at their lower ends, and the expansion occurring in freezing, forces the ice upward; the process repeating itself under favorable conditions, until the stalks or sheets of ribbed ice grow to a height of several inches. This phenomenon is especially frequent in the middle cotton States—Arkansas, Tennessee, northern Mississippi, etc., where frequent changes from rainstorms or thaws to cold northwest winds occur in winter.

CHAPTER VIII.

SOIL AND SUBSOIL.

CAUSES AND PROCESS OF DIFFERENTIATION. HUMUS.

Soil and Subsoil Ill-defined.—While the general mass of rock debris formed by the action of the agencies heretofore discussed as soil-material, may under proper conditions become soil capable of supporting useful plant growth, universal experience has long ago recognized and established the distinction between soil and subsoil: by which are ordinarily meant, respectively, the portion of the soil-material usually subjected to tillage, and what lies beneath. There can be no question about the practical importance of this distinction; but the definition of the two terms, as commonly given in some works of agriculture, is both incomplete and, in its application to many cases, partly misleading.

The differentiation of soil and subsoil is due partly to the action of organic matter and micro-organisms, partly to physico-chemical causes, now to be discussed in detail.

THE ORGANIC AND ORGANIZED CONSTITUENTS OF SOILS.

Humus in the Surface soil.—The most obvious mark of distinction between soil and subsoil is, usually, the darker tint of the former, due to the presence of humus or vegetable mold, which becomes most apparent by darkening of the tint when the soil is moistened. Thus soils having a gray tint when dry, may become almost black when wetted. When no such deepening of color occurs in wetting, the absence or great deficiency of humus may safely be inferred. The only other substance whose presence may invalidate the conclusions based upon the darkening of the soil tint, is ferric hydrate (iron rust), which itself possesses the property of darkening on wetting, and may effectually cover either the presence or the absence of humus.

Since the formation of the humus depends upon the decomposition of organic matter (mostly of the cellulose group) derived partly from the roots, partly from the leaves and stems of plants growing and dying on the soil, its accumulation near the surface is natural. But since the depth to which roots penetrate varies greatly not only with different plants, but very essentially in conformity with the greater or less penetrability of the soil and susoil, the depth to which the dark humus tint may reach vertically varies correspondingly, from two or three inches to several feet. In the case of soils that have been formed by the gradual filling-up of swamps or marshes, the humus-tint may reach to several yards depth.

Surface Soil, and Subsoil.—It is thus apparent that the term "surface soil," while commonly confined by the farmer to the portion turned by the plow or usually reached in cultivation by any implements, may or may not belong, functionally, to layers of greatly varying thickness. Similarly the term *subsoil* may or may not refer, in individual cases, to parts of the soil mass materially different from the surface soil. Yet this distinction is of no mean practical importance, because the efficacy of one of the most common measures of soil improvement, viz., subsoil plowing or "*subsoiling,*" depends materially upon the differences between soil and subsoil in each particular case. Most of the diversity of opinion regarding the merits of this operation is simply the result of a corresponding diversity in the natural facts and cultural practice of each case.

Causes of the Differentiation of Soil and Subsoil.—One of the prominent points of difference between surface soils and subsoils has already been mentioned in the usual predominance of root-mass in the upper layers; to which is added a part at least of the substance of fallen leaves and stems of its vegetation. How much of this vegetable mass ultimately becomes converted into humus, as well as the nature of the product formed, depends upon a great variety of circumstances; some of which have already been mentioned in connection with the general discussion of humification (chapt. 2, p. 20). Briefly stated, the main controlling conditions are: the amount of water or moisture present, the access of air (oxygen), a proper temperature, and the presence of the several organisms which in the course of time take part in the process of soil-formation.

Ulmin Substances; Sour Humus (Germ. Rohhumus).—In the presence of so much moisture or liquid water as will materially impede the access of air, and with the concurrence of reasonably low temperatures, the organisms that at first take the chief rôle in the transformation of the vegetable tissues into humus-like substances are bacteria. But the antiseptic nature of the compounds thus formed [1] soon puts an end to their activity, and thereafter the process seems to be a purely chemical one, and very slow. In peat bogs, the transition from the fresh, dead stems and roots to brown peat is easily followed downward, white cellulose fibers remaining apparently unchanged to some depth; so that such fiber has been used for tissues and paper. The solid decomposition-products are brown substances, partly soluble in water and imparting to it a brown or coffee color (frequently seen in the drains of marshes) and an acid reaction; the latter due to ulmic (as well as apocrenic) acid, readily soluble in caustic and carbonated alkalies, and forming insoluble salts with the earths and metals; while another portion, ulmin, is insoluble in the same, but gradually becomes soluble by oxidation.

The gaseous products formed under these conditions are carbonic dioxid and "marsh gas" (methan, CH_4), the former predominating in the early stages; while later, the carburetted hydrogen predominates, rendering the gas readily inflammable.

Sour Soils.—The "sour" soils thus produced in nature in presence of excess of water bear only "sour" growth, such as sedges and rushes, of little agricultural value; they usually require reclamation processes before becoming adapted to ordinary crops. In old forests of northern climates a peaty and more or less acid layer is sometimes formed on the surface, above the black woods-earth, and retards somewhat the full production of such land when taken into cultivation.[2]

Marshes and swamps, both fresh and salt, as above stated usually show coffee-colored waters, which are also characteristic of the streams that drain them, until by intermixture with

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[1] The antiseptic properties of sour humus are well exemplified in the perfect state of preservation in which the remains of animals, wood implements, etc., are found in bogs into which they have sunk in prehistoric times.

[2] See Müller, Natürliche Humusformen.

waters containing lime salts, the ulmic substances are neutralized and precipitated. Such neutralization, preferably by means of lime, is the first step towards the reclamation of lands bearing "sour" vegetation. The acid reaction characterizing the ulmic substances is also characteristic of many woodlands, notably in the United States of the soils of the "Long-leaf-pine" region of the Cotton States, both upland and lowland, as well as of many deciduous forests in northern climates. Hence liming, whether artificial or natural, effects a most notable improvement, together with a marked change of vegetation, in these lands.

It has been long known that after long-continued cultivation, soils originally of neutral or slightly basic reaction become acid: and the liming of such lands is an ancient practice in Europe. The matter, however, received but scant attention until Wheeler and Hartwell, of the Rhode Island Experiment Station, demonstrated the almost universal acid condition of the older lands of that State, and the excellent effects produced by neutralization with lime, or even with the alkali carbonates.[1] The current neutralization of the humus-acids is unquestionably one of the cardinal advantages of calcareous lands; for such as contain only small amounts of lime carbonate will of course become acid more quickly under cultivation.

Humin Substances.—In the presence of only a moderate amount of moisture, therefore under the influence of a more or less rapid circulation of air, and in the presence of earthy carbonates (especially that of lime) to prevent the formation of acids, or to neutralize them as formed, the normal process of humification occurs; mainly under the influence of fungous instead of bacterial growths. The various molds take a prominent part in the conversion of the vegetable substance into black, neutral, insoluble humus compounds. Such fungous vegetation is always accompanied by the evolution of carbonic gas, and the resulting fungous tissues are markedly richer in nitrogen and carbon than the substance of the higher plants from which they were derived (see chapt. 9). Comparative analyses show that in the normal process of humification of vegetable substances, oxygen and hydrogen are elimi-

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[1] Reports of the Rhode Island Exp't Station, 1895, and ff.

nated in the form of water and carbonic dioxid, while at the same time there is an increase in the percentage of carbon, and generally also of nitrogen; the latter more particularly in the case of vegetable matter not very rich in that element. When once humification is complete, oxidation, especially under arid conditions, bears mainly upon the carbon and hydrogen, so that the nitrogen content may rise to very high figures; while another portion is ultimately wholly oxidized, with the formation of nitrates, under the influence of the nitrifying bacteria, this being the process chiefly efficient in the nutrition of vegetation with nitrogen.

As a matter of course, the several organic compounds contained in plants may continue to exist in soils for some time, varying according to conditions of temperature and moisture. Thus dextrin, glucose, and even lecithin and nuclein have been reported to be found. The activity of the numerous fungous and bacterial ferments under favoring conditions will, of course, limit the continued existence of such compounds somewhat narrowly, so that they can hardly be considered as active soil ingredients save in so far as they favor the development of the bacterial flora.

Porosity of Humus.—One of the essential features of natural humus is its great porosity, whereby it not only becomes highly absorbent of water and gases, but is also gradually oxidized, probably under the influence of bacteria. For this oxidation, as measured by the evolution of carbonic gas, progresses most rapidly under the same conditions as to moisture, temperature and access of air, that are known to be most favorable to fungous and bacterial growth. Hence the formation of carbonic dioxid in the soil is assumed to be the measure of the intensity of such activity.

Physical and Chemical Nature of the Humus Substances.—The humus substances are gelatinous when moist, but are neither markedly adhesive or plastic. Like the other colloidal substances of the soil, they serve to retain both gases and vapors, including moisture, liquid water, and its dissolved solids. In the natural, porous condition they are powerfully absorbent of gases, including especially aqueous vapor. Dry humus swells up visibly when wetted, the volume-weight increasing to the extent of two to eight times; so that humus stands foremost in this respect among the soil constituents. The *density* of natural humus is about 1.4, being the lightest of the soil constituents. Hence soils rich in humus are "light" not only in the farmer's sense of being easily tilled when not too wet, but also of light weight for equal volumes when compared with clayey and sandy soils. Some data bearing upon these points are given in the table[1] below, for the substances moderately and uniformly packed:

VOLUME-WEIGHTS OF

Humus.[2]	Clay.	Quartz Sand.
.3349	1.0108	1.4485

When saturated with water, the same substances gave the following figures:

	Air-dry.	Saturated with water.	Increase. %
Humus[2]......	.3565	1.1024	209.2
Clay..........	1.0395	1.6268	55.9
Quartz sand..	1.4508	1.8270	25.9

These data show strikingly the effects produced by the several physical soil constituents upon some of its physical properties.

Chemical Nature.—While humus artificially produced by the action of caustic alkalies upon sugar or cellulose is free from nitrogen, all naturally occurring humus contains the latter.

It is not, however, present in the form of ammonia, as it cannot be set free by treatment in the cold with lime or alkalies. When, however, natural humus is *boiled* with these substances, ammonia is slowly given off, but the process continues indefinitely and it seems to be impossible to expel all the nitrogen in this manner. This behavior being characteristic of amido-compounds, it is presumable, in view of the slightly acid nature of the humus substances, that natural humus is largely of an amidic constitution. Artificial humic acid, formed by the

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[1] Wollny, Zersetzung der Organischen Stoffe, pp. 242,243.

[2] Peat pulverized and extracted with alcohol and ether to remove resinous substances.

action of caustic alkalies upon sugar, gums or cellulose, combines with ammonia as with other bases, and at first the ammonia can be readily expelled from this as from other ammonia salts. But after the lapse of some time it seems that the amidic condition is assumed, so that caustic lye acts but very slowly and cannot expel the whole of the nitrogen present. This is very important in connection with the practice of fertilization, as any ammonia taken up by or generated in the soil is thus in the course of time rendered comparatively inert, and unavailable to vegetation until nitrified.

Progressive Changes.—The natural neutral humin and ulmin, as found, *e. g.*, in the lower portions of peat beds, are in the course of time by oxidation converted into ulmic and humic acids, capable of combining with bases; by still farther oxidation they form apocrenic and crenic acids, readily soluble in water and in part forming soluble salts with lime, magnesia and other bases. These acids act strongly upon the more readily decomposable silicates of the soil, and in the course of time may dissolve out, and aid in the removal by leaching, of most of the plant-food ingredients as well as the ferric hydrate of a soil. Thus red or rust-colored soils may be rendered almost white by continued "swamping" with stagnant water, and be greatly impoverished; and it is doubtless largely through this agency that the underclays of coal beds and the lower portions of peat beds, as well as peat and coal ashes, are almost wholly destitute of mineral plant food.

The Phases of Humification.—The progressive changes involved in the process of humification of vegetable matter are illustrated in the table below,[1] together with the farther changes by which such matter may ultimately be transformed into the several varieties of coal, and finally into anthracite, which already represents nearly pure carbon, but in nature has sometimes been still farther transformed into graphite (black-lead) and diamond.

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[1] Data recalculated, omitting ash.

PROGRESS OF HUMIFICATION, AND FORMATION OF COAL.

(MOISTURE AND ASH OMITTED FROM CALCULATIONS.)

	Cellulose.	Oak Wood.			Humin and Humic Acid.	Peat.[1]			Coals.		
		Fresh.	Decayed.			Brown Surface. (Ulmin.)	Black.		Lignite Brown Coal. (Bovey).	Scotch Splint Bituminous.	Penn'a Anthracite.
			Light Brown.	Dark Brown.			40 in.	80 in.			
Carbon....	44.44	50.60	53.60	56.20	49.4 to 59.7	57.80	62.00	64.10	69.50	84.20	94.80
Hydrogen.	6.17	6.00	5.20	4.90	2.5 " 4.5	5.40	5.20	5.00	5.90	5.80	2.60
Oxygen ...	49.38	43.40	41.20	38.90	35.8 " 47.3	36.00	30.70	26.80	24.00	8.80	2.60
Nitrogen..					.3 " 18.7	.80	2.10	4.10	.60	1.20	

The steady increase of carbon and nitrogen, together with a corresponding decrease of oxygen, are well illustrated in the analyses, especially in the strictly comparable series of peat samples from various depths. In this case there is also a steady decrease of hydrogen, and an increase of ash from 2.72% in the surface layer, to 9.16 at 80 inches depth. This increase is due in the main, of course, to the progressive volatilization of the organic matter in the forms of carbonic dioxid and marsh gas (methan, CH_4).

In considering this table it should not be forgotten that while normal humus stands very close to peat, and the latter when compressed in certain stages would be undistinguishable from lignite or brown coal; yet both peat and lignite are known to be formed under conditions permitting much less access of air or oxygen than occurs in the formation of normal black soil-humus. Hence even black peat cannot at once stand in place of soil-humus when removed from its watery bed, but requires considerable time and aeration (oxidation), and in most cases neutralization with lime or marl, before it can serve the purposes of humus in the soil.

Lignite and the progressively more carbonaceous coals are and have been formed under the conjoined action of submergence and pressure, sometimes also aided by heat; and thus they cannot perform the function of soil-humus, any more than the fire-clays or shales underlying

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[1] Detmer, Landw. Versuchst., Vol. 14, 1871.

them can resume their original soil-functions without prolonged weathering.

Amounts of Humus and Coal Formed from Vegetable Matter.—Only very general and indefinite estimates can be given of the amount of humus or coal formed from a given quantity of vegetable matter, since these must vary according to the conditions under which the transformation occurs. The greater or less access of air and of moisture, the temperature and pressure under which the process occurs, will modify very materially the quantitative as well as the qualitative result. In the hot arid regions the fallen leaves may wholly disappear by oxidation on the surface of the ground, while under humid conditions they are mostly incorporated with the surface soil. If we assume that in the humification of plant debris (estimating their average nitrogen content at 1%), no nitrogen is lost, it would seem that in the humid region one part of normal soil-humus might be formed from 5 to 6 parts of (dry) plant debris; while in the extreme regime of the arid regions, from 18 to 20 parts of the same would be required. But as most probably some nitrogen also is lost in the process of humification, a considerably larger proportion of original substance may be actually required.

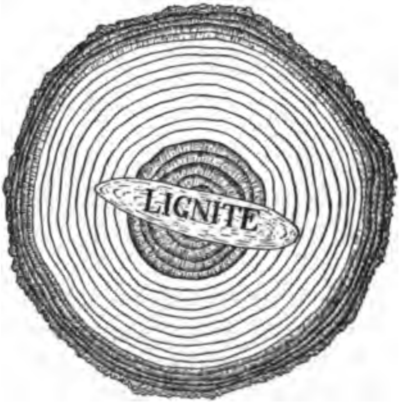

Fig. 14.—Section of lignitized log showing contraction into solid lignite on drying.

As to coal, it is usually assumed that it requires about 8 parts of vegetable matter for one of bituminous coal. Much higher estimates are made by some, and an observation made by the writer at the Port Hudson bluff, Mississippi, in 1869, would seem to justify such estimates. The above figure, from a sketch made at the time, shows the proportions to which a pine log about eight inches in diameter had shrunk in drying into a small sheet of lignitized wood; the original trunk, projecting from a bed of sand some forty feet below the surface, being so porous and spongy that when wet it flattened somewhat by its own weight; it was connected with the little sheet of lignite by a spirally twisted, tapering stipe.

Here evidently the proportion of lignite formed was a very minute one, doubtless because of the long leaching to which the trunk had been subjected. It thus seems impossible, as in the case of humus, to assign any definite proportion as between woody matter and coal formed from it.

Normal humification takes place only under the influence of moderate temperature. When the temperature is too low, bacterial and fungous growth are repressed or arrested; when too high, the fungous vegetation assumes a different phase, the result of which is the almost total oxidation of the organic matter, sometimes so accelerated as to initiate rapid combustion ("fire-fanging" of dung); leaving in any case but a trifling organic residue of very high ash contents.[1]

Eremacausis.—In the absence of a sufficient degree of moisture to co-operate with the other agencies of humification, the final result in the soil is practically the same as in the "fire-fanging" of dung. The organic matter is almost wholly destroyed by direct oxidation (eremacausis) with or without the aid of minute organisms; leaving essentially only the ash behind to be reincorporated with the soil. This is to a very great extent the predominant process in the arid regions of the Globe; most of the soils formed in these climates being, therefore, very poor in humus-substances, and deriving it almost entirely from the decay of roots only.

The extent to which the humus of a soil may be derived from the vegetable debris falling or growing upon the surface, varies greatly with the climatic conditions as well with the nature of the soil. In the forests of humid climates with loamy soils, not only does the autumnal leaf-fall, as well as decaying twigs and trunks, become obviously incorporated with the surface soil as

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[1] A striking illustration of this is afforded by Naegeli's experiment of enclosing several loaves of bread in a loosely closed tin-box. After eighteen months there remained only seventeen per cent of air-dry mouldy matter, totally destitute of starch.

decay progresses on the lower surface, but active animal agencies (see below) carry the organic remnants bodily down. But where heavy clay soils prevail, these animal agencies are much restricted by the compactness of the material; only a light surface-layer of mold would be formed, and the humus of the lower soil layers must of necessity be derived from the decay of the roots only. This origin is claimed by Kosticheff[1] for the high content of black humus in the tchernozem or black earth of Russia. Following Hellriegel in determining the weight of roots contained in successive equal layers of soil from the surface downwards, Kosticheff gives for each six inches the following data as found in the tchernozem, taking as 100 the root-content of the surface layer:

Number.	1	1	2	2	3	3
Depth.	Roots.	Humus.	Roots.	Humus.	Roots.	Humus.
6 inches.	100	5.42	100.	8.11	100.	9.64
12 "	89.1	4.83	63.9	5.19	80.3	7.77
18 "	66.9	3.62	48.3	3.92	70.0	6.71
24 "	47.3	2.56	35.0	2.84	58.4	5.61
30 "	47.3	2.59	26.0	2.11	38.2	3.57
36 "	34.6	1.88	18.1	1.47	33.0	3.18
42 "	23.9	1.29	6.3	.51	16.2	1.56
48 "	14.4	.78		.70		
54 "	6.7	.36				

It will be seen that there is a very close correspondence of the humus content with the root development in the several layers, and it seems as if though but little of the humus could be derived from the surface growth, which is that of the grasses of the steppe.

The climate of the black-earth country of Russia is, though not properly arid, yet one of rather deficient and uncertain rainfall. But as a consequence of extremely arid conditions, and in sandy lands, it may even happen that the immediate surface soil contains *less* humus than what, in the farmers' habitual parlance, would be called the subsoil; because of the penetration of slow combustion for some distance into the porous soils. It will then be lower down that, in the presence of a favorable degree of moisture and lower temperature, the conditions of normal humification are fulfilled.

[1] Abstract in Ann. de la Science Agronomique, Tome 2, 1887.

It is not always, then, that the commonly recognized distinction between surface soil and subsoil based upon humus content can be maintained. But the observation of everything bearing upon this point is of the utmost importance in determining both the agricultural value and the mode of treatment of the land.

Losses of Humus from Cultivation and Fallowing.—The fact that humus accumulates in woodlands and meadows, where no cultivation is given, would naturally lead to the converse conclusion, viz., that cultivation causes loss of humus and of its constituents. That this is actually the case is recognized and widely acted upon in practice, and there is no question that the general acceptance of stable manure as the most widely useful fertilizer, despite its usually low content of plant-food ingredients, is based upon the fact that it supplies vegetable matter, in a condition highly favorable to its conversion into humus. The most direct and cogent proof of the depletion of the soil of both humus and nitrogen by continuous cultivation of cereal grains has been given by Snyder,[1] who determined the loss both of humus and of nitrogen suffered by a Minnesota soil during eight years' continuous cultivation of wheat. The total loss of nitrogen was 1700 pounds per acre, while only 350 pounds were utilized by the crop; about 1400 pounds being dissipated as gas or leached out as nitrates. A conservative estimate of the loss of humus suffered during the same period was about a ton per acre annually, and this loss seriously decreased not only the nitrogen-content, but rendered the soil more compact and less retentive of moisture. But by rotation of the wheat with clover in alternate years, very nearly an equilibrium of both humus and nitrogen-content was obtained. In addition, the amount of available mineral plant-food was decreased by continuous grain culture. Ladd has made similar observations in North Dakota, with similar results.

That excessive aeration results in serious losses of humus as well as of nitrogen, is very obvious in the arid region, where it is the habit to maintain on the surface of orchards and vineyards during the dry, hot summers, a thick mulch of well-tilled soil, thus preventing loss of water by evaporation. In the course of years this surface soil becomes so badly depleted

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[1] Bull. No. 70 Minn. Exp't Station, 1905.

of humus that good tilth becomes impossible, the soil becoming light-colored and compacted; while the loss of nitrogen is indicated by the small size of the orchard fruits. Similar losses are of course sustained in the practice of bare summer-fallow, which at one time was almost universal in portions of the arid region. The complete extirpation of weed growth thus brought about, at first considered an unmixed benefit, has ultimately had to be made up for by the practice of green-manuring; since in the arid region the use of stable manure encounters many difficulties.

Estimation of Humus in Soils. It has been usual to determine the amount of humus in soils by means of (dry or wet) combustion, calculating the humus from the carbonic dioxid so formed, while measuring the nitrogen gas directly. But in this process the entire organic matter of the soil, humified and unhumified, is indiscriminately included; and it is wholly uncertain to what extent the latter will ultimately become humus, from the nitrification of which plants are presumed to chiefly derive their nitrogen.[1] In order to obtain definite results, the actual, functional humus must be extracted from the soil mass by some solvent which discriminates between the humified and unhumified organic matter. This cannot be done by direct extraction with caustic soda or potash, which inevitably dissolve unhumified matters and tend to expel ammonia from the humus; besides themselves acting as humifiers (see this chapter, p. 125.)

Grandeau Method: Matière Noire.—The only method now known which accomplishes this separation, practically excluding the unhumified while fully dissolving the humified matter—is that of *Grandeau:* the extraction of the soil, first with dilute acid, in order to set the humic substances free from their combinations with lime and magnesia; and their subsequent extraction with moderately dilute solutions of ammonia (or other alkali hydrates). Upon the evaporation of the ammonia-solution the humus is left behind in the form of a black lustrous substance (" matière noire " of Grandeau) much resembling the crust of soot formed in flues from wood fires. As it contains a variable amount of ash, it must be burnt and the ash subtracted from the first weight.

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[1] The humus determinations thus made, which include nearly all those made by German chemists, give the humus-content from 40 to 50°/₀ too high. The French determinations are mostly made by the method of Grandeau.

Amounts of Humus in Soils.—While in peat, marsh and muck lands the humus-content may rise above twenty per cent, in ordinary cultivated lands it rarely exceeds about five per cent, and very commonly falls below three per cent, even in the humid regions. In properly arid soils we find a very much lower average, rarely exceeding one per cent, and frequently falling to .30 and even less. This scarcity of humus manifests itself plainly in the prevalently light gray tint of the arid soils.

Meadows and woodlands generally show the highest humus-content in their surface soils, gradually increasing while in that condition; while when taken into cultivation the humus-content gradually decreases, owing to the free aeration and consequent "burning-out" caused by tillage. Hence the humus must be from time to time replaced by the use of stable manure, or green-manure crops, to prevent injurious changes in the tilling qualities of the land. Not only humus as such, but according to Schloesing also the insoluble colloid humates, produce in the soil a loosening effect or tilth (Germ. Bodengare), which apparently cannot be brought about by any other substance.[1]

Humates and Ulmates.—That the insoluble humates of lime, magnesia, iron, manganese and alumina are present in most soils is conclusively shown by the composition of the solution obtained by the extraction of soils with weak acid, as above mentioned in connection with the quantitative determination of humus according to Grandeau; since these bases are almost always extracted by the weak acid. When the brown solution of alkali humate obtained in this process is carefully neutralized with sulfuric or hydrochloric acid, or is mixed with solutions of the above bases, flocculent, insoluble precipitates are formed, while the solution is discolored. Similar precipitates may be obtained with other metallic solutions, notably with that of copper, which precipitates the humus-acids most completely. Doubtless these compounds contribute greatly to the conservation of the humus-content of soils, protecting it to a certain extent from oxidation, and also preventing excessive acidity. The brown tint of certain subsoils in the northern humid re-

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[1] The decrease of humus from wheat culture in the soils of Minnesota and North Dakota has been studied by H. Snyder and E. F. Ladd, respectively. In the prairie lands of the latter State the total organic matter in the first six inches of soil ranges fram 15 to as much as 26°/₀, and the humus alone from 4 to 7.8°/₀.

gions have been shown by Tollens and others to be due not to ferric hydrate, as had been supposed, but to calcic, magnesic and aluminic humates. *None of the mineral bases or acids present can be detected in the humic solution by the usual reagents.*

Mineral Ingredients in Humus.—That the mineral plant-food ingredients present in the humus extracted by the Grandeau process, and which remain as ash when the matière noire is burned, are capable of nourishing plant growth, was directly shown by Grandeau, Snyder and others. The former was inclined to consider that those substances were mainly thus taken up by plants, under natural conditions. This theory, however, has not been sustained by subsequent investigations; the mineral plant-food thus extracted is not a measure of the immediate productiveness of the soils, as demonstrated by Snyder, and the residual soils are not sterile. It is also still doubtful to what extent the mineral bases and acids are *naturally* combined with the humus-substances, it being contended by some that they are brought into organic combination by the acid and ammonia extraction. The investigations of Snyder and Ladd, above referred to, prove however to some extent at least that the humus-substances are naturally combined with them, and that probably they are largely made available to plants through the direct and indirect action of the humus compounds. This subject is farther considered in chapter 19.

The nature and amounts of these mineral substances are well exemplified in the subjoined full analysis by Snyder, of the ash of the humus and humates extracted from a compound sample of prairie soils of Minnesota, which had been thrown down from the ammonia solution by simply neutralizing the liquid:[1]

ASH OF HUMUS FROM MINNESOTA PRAIRIE SOILS.

Insoluble matter[2]	61.97
Potash (K_2O)	7.50
Soda (Na_2O)	8.13
Lime (CaO)	0.09
Magnesia (MgO)	0.36
Peroxid of Iron (Fe_2O_3)	3.12
Alumina (Al_2O_3)	3.48
Phosphoric acid (P_2O_5)	12.37
Sulfuric acid (SO_3)	.98
Carbonic acid (CO_2)	1.64

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[1] Precipitation with an excess of acid does not greatly change the results.

[2] In California soils this is mostly silica soluble in carbonate of soda.

The large amounts of the soluble alkalies potash and soda thrown down with the humic matters are very striking, as is the very large proportion of phosphoric acid. Lime and magnesia had, of course, been mainly eliminated by the preliminary acid treatment.

Functions of the Unhumified Organic Matter.—The unhumified plant debris in the soil are not to be regarded as useless, even aside from their potential conversion into active humus. Not only do these remnants of vegetation lighten the soil, rendering it more pervious to air and water, but in their progressive decay they give off carbonic gas, which is active in soil-decomposition; and they serve as nourishment to the soil bacteria upon which its thriftiness so greatly depends. See below, chapter 9.

The Nitrogen-Content of Humus.—Since soil-humus is doubtless the chief depository of soil-nitrogen, and the main source from which, through the process of nitrification, the nitrogen-supply to plants is usually derived, its content of that element is a matter of great interest. It has been customary to estimate approximately the nitrogen-content of soils by the proportion of humus-substance present; and as the light tints of the soils of the arid region indicate a small humus-content, a scarcity of nitrogen seemed to be also indicated for these lands. As this in a number of cases did not seem to accord with actual experience, an investigation of the subject was made at the California experiment station,[1] with the results shown in the subjoined table. In considering these results it must be kept in mind that while arid conditions can rarely be fulfilled in the humid region, humid conditions are quite frequently locally represented in the arid, in lowlands and on high mountains; while moderately moist benchlands represent the semi-arid regime.

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[1] *Hilgard and Jaffa.* On the Nitrogen-content of Soil-humus in the Humid and Arid regions. Rep. Cal. Exp't Station for 1892–4; Agric. Science, April, 1894; Wollny's Forsch. Geb. Agr. Phys., 1894.

HUMUS PERCENTAGE AND NITROGEN CONTENT IN SOILS OF THE ARID AND HUMID REGIONS.

Station Number	Soils arranged in order of nitrogen percentages in humus.	Humus in soil, per cent.	Nitrogen in Humus, per cent.	Nitrogen in soil, per cent.
	SOILS OF THE ARID REGION (California).			
2061	Dark clay loam, Arroyo Grande Valley, San Luis Obispo County	3.06	22.00	.670
2291	Red soil, Orland, Glenn Co	.71	21.10	.150
1904	Sediment Soil, Porterville, Tulare Co	.90	19.50	.180
1901	Sandy soil near Ceres, Stanislaus Co	.64	18.75	.120
704	Sandy soil of plains, near Fresno, Fresno Co	.60	18.66	.112
6	Black adobe soil, Stockton, San Joaquin Co	1.05	18.66	.196
1679	Black adobe soil, Berkeley, Alameda Co	1.20	18.58	.203
2324	Clay soil of desert, Imperial, San Diego Co	.38	18.40	.070
1167	Black clay loam soil, near Tulare, Tulare Co	1.66	18.19	.302
1536	Brown loam soil, Windsor Tract, Riverside, Riverside County	.20	18.00	.036
1126	Sandy loam soil, Paso Robles, San Luis Obispo Co	.55	17.27	.095
2301	Red hill soil, Upper Lake, Lake Co	.81	16.90	.137
1607	Plateau soil of desert, Lancaster, Los Angeles Co	.25	16.80	.042
1159	Sandy plains soil, Tulare, Tulare Co	.37	16.75	.062
1900	Sandy soil, near Modesto, Stanislaus Co	.84	16.65	.140
1113	Clay loam soil (slate), Jackson, Amador Co	.54	16.60	.090
1149	Adobe clay soil, near Paso Robles, San Luis Obispo County	.47	16.18	.074
1538	Mesa soil, Chino, San Bernardino Co	.65	16.08	.105
1147	Sandy loam soil, Paso Robles, San Luis Obispo Co	.66	16.06	.106
2403	Valley Soil, Wheatland, Yuba Co	1.50	16.00	.240
1281	Red Mesa soil, Pomona, San Bernardino Co	.58	15.50	.090
1117	Sandy granitic soil, near Jackson, Amador Co	.80	15.27	.123
1406	Red loam soil, Arlington Heights, Riverside, Riverside County	.30	15.00	.045
1172	Red clay loam soil, east of Tulare, Tulare Co	.72	14.75	.106
1958	Sandy Mesa soil, Nipomo, San Luis Obispo Co	.85	14.45	.122
1423	Chocolate-red soil, Carisa plain, San Luis Obispo County	.39	14.36	.056
1291	Sandy hill land, near Jackson, Amador Co	.76	14.34	.109
585	Wire-grass loam soil, Visalia, Tulare Co	1.00	14.10	.146
863	Red ridge loam soil, Grass Valley, Nevada Co	2.89	13.91	.402
1907	Dark loam soil, near Chino, San Bernardino Co	.92	13.26	.121
1115	Sandy granitic soil, near Jackson, Amador Co	.85	13.20	.112
332	Plateau desert soil, Mojave, Los Angeles Co	.28	12.50	.035
2126	Gravelly soil, East Highlands, San Bernardino Co	.62	11.75	.070
1910	Ojai Valley soil, Nordhoff, Ventura Co	1.64	11.21	.183
2187	Sandy loam soil, Soledad, Monterey Co	.97	11.10	.110
1759	Sandy soil, Perris Valley, Riverside Co	.53	11.04	.059
774	Bench slope soil, Ontario, San Bernardino Co	1.29	10.85	.140
1984	Red soil, East Highlands " " "	.58	10.50	.060
2325	Silt soil of desert, Imperial, San Diego Co	.65	10.70	.070
1906	Light sandy soil, Pomona, San Bernardino Co	.95	9.80	.093
2430	Hillside adobe, Berkeley, Alameda Co	1.85	8.70	.160
	Average of arid uplands	.91	15.23	.135

HUMUS PERCENTAGE AND NITROGEN CONTENT IN SOILS OF THE ARID AND HUMID REGIONS.

Station Number	Soils arranged in order of nitrogen percentages in humus.	Humus in soil, per cent.	Nitrogen in Humus, per cent.	Nitrogen in soil, per cent.
	SUB-IRRIGATED ARID SOILS (California).			
586	Sandy plains soil, Tulare, Tulare Co....	1.14	10.79	.123
1466	Loam soil, Miramonte, Kern Co....................	.60	10.66	.064
1284	Moist land loam soil, Chino, San Bernardino Co......	1.99	10.20	.203
1148	Swale soil, near Paso Robles, San Luis Obispo Co.....	1.16	9.65	.112
1714	Bench soil, Santa Clara River, Piru, Ventura Co.......	.78	9.56	.074
77	Alluvial soil, Tulare Lake bed, Tulare Co............	.47	9.37	.045
1880	Creek bench soil, Niles, Alameda Co................	1.19	8.90	.109
1903	Sediment soil, Porterville, Tulare Co................	1.12	8.50	.140
168	Alluvial soil, Santa Clara river, Santa Paula, Ventura Co	.84	7.99	.067
1760	Green-sage land, Perris Valley, Riverside Co..........	.91	7.70	.070
506	Alluvial soil, Colorado River, Yuma, San Diego Co....	.75	7.47	.050
1636	Red soil, Manton, Tehama Co.......................	2.00	6.86	.137
1758	Alkali soil, Perris Valley, Riverside Co..............	.60	6.83	.071
1963	Sandy loam soil, Willows, Glenn Co................	.36	6.05	.022
2080	Sandy soil, Santa Maria Valley, Santa Barbara Co.....	1.64	5.36	.090
	Average of sub-irrigated arid soils............	1.06	8.38	.099
	HUMID SOILS FROM ARID AND HUMID REGIONS (California).			
207	Eel River Alluvial soil, Ferndale, Humboldt Co........	1.25	6.96	.085
2319	Alluvial soil, Hupa Valley, Humboldt Co.............	7.83	6.70	.514
213	Marsh soil, Novato, Meadows, Marin Co.............	1.54	6.36	.089
1704	Valley soil, Hollister, San Benito Co................	.94	5.21	.049
2295	Tule soil, Upper Lake, Lake Co.....................	1.70	4.50	.077
110	Alluvial soil, Putah Creek, Dixon, Solano Co.	1.71	4.25	.072
37	Redwood Valley soil, Pescadero, San Mateo Co.......	2.28	3.07	.070
	Average for California....................	2.45	5.29	.135
	OTHER STATES.			
26	Bog soil, Michigan................................	[2] 33.02	6.08	[2] 2.012
	Back-land clay loam, Houma, Louisiana..............	5.07	4.20	.218
	Duff soil, Oregon..................................	13.84	3.49	.483
	Sandy prairie soil, Harris Co., Texas.................	2.13	3.66	.184
	Average for other States.................	7.01	3.78	.295
23	Red soil, Oahu Island, Hawaii (maximum)...........	1.57	5.07	.078
27	Guava soil, Hawaii Island (minimum).................	9.95	1.71	.170
	Average of 5 soils, Oahu Island......................	3.01	6.07	.237
	Average of 2 soils, Maui Island......................	9.07	2.13	.286
	Average of 4 soils, Hawaii Island....................	6.17	2.54	.146
	Average for Hawaiian Islands.............	5.26	3.69	.169
	Total for Humid soils, average............	4.58	4.23	.166

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[2] Introduced only for comparison of the nitrogen percentage in Humus and not included in the average.

It thus appears that on the average the humus of the arid soils contains about three and a half times as much nitrogen as that of the humid; that in the extreme cases, the difference goes as high as over six to one (see Nos. 37 and 704); and that in the latter cases, the nitrogen-percentage in the arid humus considerably exceeds that of the albuminoid group, the flesh-forming substances.

It thus becomes intelligible that in the arid region a humus-percentage which under humid conditions would justly be considered entirely inadequate for the success of normal crops, may nevertheless suffice even for the more exacting ones. This is more clearly seen on inspection of the figures in the third column, which represent the product resulting from the multiplication of the humus-percentage of the soil into the nitrogen-percentage of its humus; as appears in comparing the respective averages, or Nos. 1167 and 110 and others. An additional consideration is the probable greater ease with which the nitrifying bacteria can act upon a material so rich in nitrogen.

We must not, then, be misled by the smallness of many humus-percentages in the arid region, into an assumption of a deficiency in the supply of soil-nitrogen.

Decrease of Nitrogen-Content in Humus with Depth.—Since the oxidation of the carbon and hydrogen in the humus-substance, and the consequent increase of its relative nitrogen-content, are manifestly dependent upon the presence of air and heat, it is reasonably to be expected that the nitrogen-percentage of the humus should decrease with the depth of the soil. That this is really the case is plainly shown in the subjoined table, which gives the humus-percentages and the nitrogen-content of the humus from the surface foot down to twelve feet, in a soil on the bench of the Russian River, Cal., which is sub-irrigated, and liable to more or less rainfall during the summer. It will be seen that not only does the absolute humus-percentage decrease quite regularly down to seven feet, at which point there evidently was at one time a strong root development, causing a notable increase of the humus-content; from which again there is a regular decrease down to the twelfth foot. It will be noted that the nitrogen-percentage in the humus, while not decreasing with the same regularity as the humus-content itself, yet exhibits a general recession from 5.30 to 1.15 in the ninth foot, to which direct oxidation doubtless never penetrates.

HUMUS AND NITROGEN-CONTENT OF RUSSIAN RIVER SOIL.

Depth in feet.	Per cent Humus in soil.	Per cent Nitrogen in Humus.	Per cent Humus-Nitrogen in soil.
1	1.21	5.30	.064
2	1.16	4.32	.054
3	1.14	3.87	.044
4	1.17	3.76	.044
5	.74	2.16	.016
6	.60	2.66	.016
7	.47	2.54	.012
8	.78	1.54	.012
9	.54	2.24	.012
10	.52	1.15	.006
11	.53	1.51	.008
12	.44	1.81	.008

Influence of the Original Materials on the composition of Humus.—The great variability of the composition of humus formed from different substances is well shown in the subjoined table, representing the results of experiments made by Snyder,[1] who caused various substances to humify by mixing the pulverized material intimately with a soil poor in humus, and allowing the process to continue for a year. At the end of that time the humus formed was extracted by the method of Grandeau, outlined above, and analyzed, with the following results.

	Sugar.	Oat Straw.	Green Clover.	Wheat Flour.	Saw-dust.	Meat Scraps.	Cow Manure.[2]
Carbon........	57.84	54.30	54.22	51.02	49.28	48.77	41.93
Hydrogen......	3.04	2.48	3.40	3.82	3.33	4.30	6.26
Nitrogen.......	.08	2.50	8.24	5.02	0.32	10.96	6.16
Oxygen........	39.04	40.72	34.14	40.14	47.07	35.97	45.63
	100.00	100.00	100.00	100.00	100.00	100.00	100.00

While it may be questioned whether the process of humification had in these materials really reached the point of sensible completion in all cases (notably in those of sawdust and cow

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[1] Bull. No. 53, Minn. Exp't Station, p. 12, Chem. of Soils and Fertilizers, p. 94.

[2] The figures for cow manure are so far out of range with any others thus far observed, that it seems reasonable to suppose that they are influenced by unchanged substances present in the excreta.

manure), the great variability of the products from different materials is very striking. When the nitrogen-content is deducted the percentage composition of the products agrees more nearly. Considering that the nitrogen is probably present in the amid form, it is natural that hydrogen should in a measure vary with it, as in the case of the clover, flour and meat humus. Nitrogen being the most variable ingredient of humus, it seems probable that the variation of the proportion of the humus-amids present is the most potent factor in the variability of the composition of natural soil-humus.

Arranging these results in the order of their nitrogen-content as in the table below, we see that the latter approximately corresponds to the original protein-content of the humified substances.

Humus from meat scraps	**10.96**	**% Nitrogen.**
" " green clover	8.24	
" " cow manure	6.16	
" " wheat flour	5.05	
" " oat straw	2.50	
" " sawdust	.32	

While the above data prove the correlation between the first products of humification and the original substance, it must be remembered that subsequently, under proper conditions, the nitrogen-percentage in humus may, in the course of time, increase very greatly, even to a proportion considerably above that contained in flesh itself. When we consider that ordinarily, the latter, and the albuminoid substances generally, decompose in contact with air with an abundant evolution of ammonia compounds, sometimes leaving only a little fat (adipocere) behind, it is surprising that the decomposition *within* the soil should have exactly the opposite result, viz., an *accumulation* of the nitrogen. The causes of this marked difference are not yet well understood, but it is probably due to the differences in the kinds of bacteria that are active in the two cases.

Snyder has also shown that the richer the organic matter humified is in nitrogen, the more energetically it acts in rendering available the mineral matters of the soil for plant nutrition.

Correspondingly, Ladd[1] has shown that with the increase of humus in the soil, there is also a corresponding increase in the amounts of mineral plant-food extracted from the soil by a four per cent solution of ammonia, such as is employed in the Grandeau method of humus-determination.

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[1] Bull., S. Dakota Station, Nos. 24-32, 35, 47.

CHAPTER IX.

SOIL AND SUBSOIL (*Continued*).

ORGANISMS INFLUENCING SOIL CONDITIONS; BACTERIA, ETC.

MICRO-ORGANISMS OF THE SOIL.

INTIMATELY correlated with the humus-substances of the soil, as well as with its temporary contents of the carbohydrates (cellulose, gums and sugars) from which humus is formed, is the multitudinous flora of micro-organisms always present and exercising important functions in connection with the growth of the higher plants. Extended researches by Adametz, Schloesing and Müntz, Miquel, Koch, Fraenkel, Winogradsky, Frank and many others, have thrown light upon the immense numbers and great variety of minute organisms, especially of the bacterial group, present in soils, and upon their distribution and activities in the same. It has been shown that their numbers are greatest near (although usually not *at*) the surface, decreasing rapidly downward and generally disappearing wholly at depths between seven and eight feet; the latter depth varying of course according to the nature and porosity of the soil, and both depth and numbers being greatest in summer.

Numbers of Bacteria in Soils.—Adametz found in one gram of soil, 38,000 bacteria at the surface, 460,000 at ten inches depth; in a loam soil at the surface 500,000, at ten inches 464,000 in each gram of earth. Of mould and similar fungous germs there were only 40 to 50 in the same, 6 species being true molds, while four were ferments, including the yeasts of wine and beer. Fraenkel found in virgin land from near Potsdam, a sudden, marked decrease at depths of from three to five feet; while in earth from inhabited places within the city of Berlin, considerable numbers were still present at eight and even ten feet, in some cases.

In the researches lately made by Hohl at the bacteriological station at Liebefeld, near Bern, it was found that in cultivated soils the number of bacteria greatly exceeds the figures given by Fraenkel. He found a gram of moist soil to contain from three to fifteen millions of bacteria. In the cultivated soil of Liebefeld he found 5,750,000, in meadow land 9,400,000, in a manure pile 44,500,000 per cubic centimeter. These figures seem high for so small a quantity of material, but taking the average size of a bacterium, a cubic centimeter might readily contain six hundred millions. (Grandeau, Ann. Sci. Agronomique, vol. 1, p. 461, 1905).

Mayo and Kinsley (Rep. Kansas Exp't Station for 1902-3) have made elaborate investigations of the numbers and kinds of bacteria found in various soils in Kansas, in connection with different crops. It is noteworthy that in most cases their figures exceed considerably those given by European observers, as they often reach high into the millions, in one case to over fifty millions, per cubic centimeter.[1]

Five fields with different soils were investigated; the land being described as follows: "Field No. 1 is a black loam containing considerable humus; field No. 2 is similar to field 1 but contains more humus; field No. 3 is a thin soil with clay gumbo subsoil; fields Nos. 4 and 5 are black loams, but not as rich in humus as either No. 1 or No. 2."

The average bacterial contents of the several fields are given as follows:

Field No. 1	33,931,747	per cubic centimeter.
" No. 2	53,596,060	" " "
" No. 3	78,534	" " "
" No. 4	8,643,006	" " "
" No. 5	3,192,131	" " "

"The crop records of these fields for the past ten years indicate that the crop yield has been (more or less ?) directly proportional to the bacterial content of the soil of each field; field 2 has produced the largest yield, field 3 the least."

Unfortunately no chemical analyses of any of these soils are communicated; but at the request of the writer samples of the soils of the

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[1] The mode of statement in the paper is not always quite clear as to the manner in which the averages given were calculated. It must be remembered that these data refer to cubic centimeters of soil, or about twice the amount (1 gram) used by European observers.

first three fields were sent from the Kansas station for humus determinations (courteously made by Dr. H. C. Myers), which gave the following results:

Field	No. 1	2.19%	of Humus.
"	No. 2	3.07%	" "
"	No. 3	1.85%	" "

While these humus-percentages are not directly proportional to the bacterial content, a favoring effect of high humus-content is clearly shown. The bacterial and the humus-content of these soils are sensibly, even if not directly, correlated; which might reasonably be expected, since the organic matter and the humus are the bacterial food.

The investigation also showed wide differences in the bacterial content of the same soil when different crops were growing on it. Thus in samples taken on Aug. 15, there were found in the first twelve inches of a black loam soil bearing timothy and clover, 1,380,000, in the same with alfalfa and clover, 21,091,000, with maize from one to over two millions. In soils from the western part of Kansas, the bacterial content of the same crops was much less (as doubtless is the humus-content), and it is noteworthy that the prairie buffalo grass shows throughout a relatively high bacterial content in the first foot of the soil, ranging next to alfalfa. The root bacteria living on the legumes will naturally increase the bacterial content of the soils on which they grow, more than plants which, like maize, do not directly utilize bacterial action.

Multiplication of the Bacteria.—Marshall Ward and Duclaux have made some special observations in regard to the rapidity with which certain bacteria multiply. Duclaux summarizes the final conclusion thus: taking as a basis the time of 35 minutes for the subdivision into two, which has been frequently observed by Ward, there would be four millions of bacteria produced in twelve hours. The first filaments had plenty of room in a drop culture of one cubic millimeter; but at the end their total volume amounted to the tenth part of the total volume of the drop. At the above rate, making 48 generations in 24 hours, 281,500 billions of organisms would be produced. (Grandeau, Ann. Sci. Agron. Vol. 1, 1905, p. 456).

Aerobic and Anaerobic Bacteria.—As may readily be inferred, the cultural and other surface conditions exert a potent influence both upon the kinds and abundance of the bacteria and molds; since the life-functions of some are dependent upon the presence of free oxygen ("aerobic"), while others flourish best, or only, in the absence of air ("anaerobic"), or are able to avail themselves of the presence of *combined* oxygen, by reduction of oxids present. Their number is found, in general, to be greatest in cultivated lands, and bacteria are there by far predominant over the moulds. On the other hand, the moulds gain precedence in woodlands and meadows, at least so far as air can gain access; while in the deeper layers of the same, as well as in peaty lands, bacterial life is always scanty. This holds particularly in respect to the nitrifying organisms, and others whose life-functions are dependent upon abundant access of oxygen (aerobic).

Food Material Required.—All bacteria, like the fungi, are dependent for their development upon the presence of adequate amounts of some organic food-material, best apparently in water-soluble form. In the soil it seems to be chiefly compounds of the carbohydrate group, especially various gums derived from the decaying plant substance, or from stable manure; in artificial cultures, glucose is mostly found to be a highly available food. When the decaying substance reaches the state of humus, the latter seems to be available as food only to comparatively few bacteria. The very abundant development of bacterial life seems to be among the most important effects produced by stable manure upon the surface soil, in establishing good tilth ("Bodengare" in German).

Functions of the Bacteria.—While there is still much uncertainty as to the exact functions performed by most of these bacteria in respect to soil-formation and plant growth, there are several kinds whose activity has been proved to be of the utmost importance in one or both directions; it having been shown that when the soil is sterilized either by heat or antiseptic agents, certain essential processes are completely suppressed until the soil is re-infected and the conditions of bacterial life restored.

Probably the chief in importance are those connected with the processes of *nitrification* and *denitrification*, bearing as they do upon the supply to plants of the most costly of the three substances furnished by fertilizers. These organisms have been first extensively studied by Winogradsky, while the conditions of their activity have been largely developed by R. Warington.

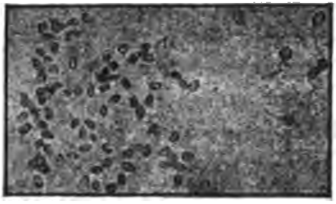

FIG. 15.—Nitrosomonas. (Winogradsky).

FIG. 16.—Nitrobacterium. (Winogradsky).

Nitrifying Bacteria.—The conversion of ammonia into nitrates is accomplished under proper conditions by two organisms, or groups of organisms; the first stage being the formation of nitrites by the round, often flagellate cells of *nitrosomonas* (or nitrosococcus). The second, the oxidation of the nitrites into nitrates by very minute rod-shaped bacilli, named *nitrobacteria*. The conditions under which these bacteria can act are quite definite in that, aside from a supply of the nitrifiable substance, a fairly high temperature (24° C. or 75° F.) and a moderate degree of moisture, there must be a free access of oxygen (air); and there must be present a base (or its carbonate) with which the acids formed by oxidation can immediately unite. In an acid medium ("sour" soils) nitrification promptly ceases; as it also does whenever the amount of base present has been fully neutralized. The bases most favorable to nitrification are lime and magnesia in the form of carbonates, an excess of which does no harm; while in the case of the carbonates of potash and soda, the amount must be strictly limited.

Conditions of Activity.—Dumont and Crochetelle found that up to .25 per cent, potassic carbonate acted favorably on the process; which was, however, completely stopped by as much as .8 per ct. Warington has shown that ammonic carbonate similarly prevents nitrification when exceeding about .37 per ct. Ammonia salts in general appear to be antagonistic to the transformation of nitrites into nitrates.

Aside from the carbonates, some neutral salts favor nitrification very markedly; while others tend to depress it. Deherain found that .5 per cent of common salt suffices to prevent nitrification altogether, while smaller amounts retard it proportionally. According to Dumont and Crochetelle, potassium chlorid acts favorably up to .3 per cent, but at .8 per cent. suppresses nitrification. Earthy and alkaline sulfates, on the contrary, seem to act favorably throughout, at least up to .5 per cent. this is especially true of gypsum, which, according to Pichard, accelerates the process more than any other substance known. Taking the effect of gypsum as the maximum, he found that, other things being equal, the amounts of nitrates formed were as shown in the table below, the effect of gypsum being taken as 100:

Gypsum	100
Sodic Sulfate	47.9
Potassic Sulfate	35.8
Calcic Carbonate	13.3
Magnesic Carbonate	12.5

The above estimates are markedly confirmed by the observations of the writer in the alkali soils of California. In these, nitrates exist most abundantly when the salts contained in the soil are mainly sulfates; while wherever common salt or sodic carbonate are present in considerable amounts, the amounts of nitrate found are notably less. In saline seashore lands nitrates are usually present in traces only. Wollny has moreover shown that the nitrates themselves exert a repressive influence on nitrification.

Effects of Aeration and Reduction.—While the fostering effect of sulfates upon nitrification is very energetic in well aerated soils, they become injurious whenever by a reductive process in ill-drained lands, the sulfates are reduced to sulfids. Under such conditions the process will in any case be much impaired. On the other hand, the favoring effect of abundant aeration was strikingly shown in the experiment made by Deherain, in which a cubic meter of soil was left unmoved for several months, while a similar mass was thoroughly agitated once a week during the same time. The proportion of nitrates formed in the latter case was as 70 to 1 formed in the quiescent soil mass. It follows that the intensity of nitrification is essentially dependent upon the porosity of the soil; and that it is thus greatly favored in the pervious soil-strata of the arid regions. It also follows that thorough and frequent tillage and fallowing greatly favor nitrification; thus explaining one of the beneficial results of these operations. At the same time, it is true that we may thus in a short time seriously diminish the reserve stock of nitrogen contained in the soil in the form of humus-amids; and since nitrates are exceedingly liable to be lost from the soil in several ways, such excessive nitrification is to be avoided.

Unhumified Organic Matter does not Nitrify.—There can be little doubt that the formation of ammonia from the amido-compounds in humus is also the work of bacteria; but this, really the initial phase of the nitrogen-nutrition of plants, has not yet been fully elucidated. That, however, it is essentially only the ready-formed humus and not the unhumified debris of the soil which participate in nitrification was shown by the experiments of the writer, see chapter 19.

Denitrifying Bacteria.—Among the sources of *loss of nitrates* in the soil is the action of denitrifying bacteria; some of which cause merely the reduction of nitrates to nitrites and progressively to ammonia, while others cause gaseous nitrogen to be given off from nitrites and nitrates, resulting in their complete loss to the soil. While there are probably several kinds of the latter class, the most rapidly effective is an organism contained abundantly in fresh horse dung, and also on the surface of old straw. This can readily be shown by subjecting a very dilute solution (1-3 per cent.) of Chile saltpeter to the action of fresh horse dung in a close flask, when nitrogen and carbonic dioxid gases are evolved, and in a few days the nitrate has totally disappeared. In the course of time this power of horse-manure disappears; so that "rotted manure" is practically free from it and under proper conditions serves nitrification so effectively, that in the past it has served extensively for the production of saltpeter in the "niter-plantations" for the industrial purposes; the material of which was loose


Fig. 17.—Bacillus denitrificans I. (Burri.)

earth, marl and manure, kept moist and frequently forked over for better aeration. Saltpeter is similarly produced in stables, corroding the mortar of brick foundations. Nevertheless, it is necessary to avoid the use, either together or at short intervals apart, of Chile saltpeter and fresh manure; the manure if used first should be allowed to remain at least two months in the soil before saltpeter is applied.

The reduction of nitrates to nitrites and ammonia is brought about by quite a number of bacteria, mostly anaerobic, and such as consume combined oxygen in their development. Thus the butyric ferment, which in the absence of readily reducible compounds evolves free hydrogen, will in presence of nitrates reduce the latter to nitrites, or form ammonia by addition of hydrogen to nitrogen just set free by reduction. Such reductive processes of course occur chiefly in soils rich in organic matter, or ill-aerated. The ammonia so formed, while at first simply combining with any humus acids present, may in the course of time be itself reduced to the amidic condition, being thereby rendered relatively inert, until again brought into action by ammonia-forming bacteria.

Ammonia-forming Bacteria.—A large number of different bacteria appear to be concerned in the formation of ammonia from compounds of the albuminoid group, (and probably from humus). Among these is one of the most common in soils (*Bacillus mycoides,* root bacillus), which while forming ammonia carbonate in solutions of albumen, is also capable of reducing nitrates to nitrites and ammonia in presence of a nutritive solution of sugar.

The "hay bacillus" (*B. subtilis*), so abundantly developed in hay infusions, and one of the most abundant in cultivated soils, has together with B. ellenbachensis, B. megatherium, B. mycoides, and others, by some been credited with important action in favoring vegetation; so that a fairly pure culture of B. ellenbachensis has been brought out commercially in Germany under the name of "Alinit." Rigorous culture experiments made by Stutzer and others have, however, failed to show any general benefit from the use of alinit in infecting either land or seeds. But there is no doubt of the

Effects of Bacterial Life on Physical Soil Conditions.—It is apparent that all conditions favoring the life of aerobic (air-needing) bacteria tend also to produce the loose, porous state (tilth) of the surface soil so conducive to the welfare of culture plants, designated by German agriculturists as "Bodengare." Whether or not this condition is directly due to bacterial processes, as is thought by Stutzer (Landw. Presse, 1904, No. 11) it is assuredly a highly important point to be gained, and is essentially connected with the presence of humus in adequate amounts, which is also a favoring condition of abundant bacterial life. It seems that the preference given to the shallow putting-in, or even surface application of stable manure, existing in Europe, is largely based upon the marked effect upon the looseness of the surface soil, generally credited to the physical effect of the manure substance itself, but apparently largely due to the intensity of bacterial action thus brought about.

Fig. 18.—Bacillus subtilis. (Wollny, after Brefeld.

Fig. 19.—Bacteria producing ammoniacal fermentation: *A, C. mycoides: B, B. stutzeri.* (From Conn, Agr. Bacteriology.)

ROOT-BACTERIA OR RHIZOBIA OF LEGUMES.—Among the most important bacteria, agriculturally, is that which enables plants of the leguminous order—(peas, beans, vetches, clovers, lupins, etc.),—to obtain their supply of nitrogen from the air independently of those contained in the soil. The source of nitrogen to plants was long a disputed question; it was at first supposed (by de Saussure) that it was obtained directly from the soil by the absorption of humus; but this was disproved, and Liebig then contended that it was derived directly from the atmos-

Fig. 20.—Bacillus magaterium. (From Migula.)

phere through the ammonia in rain water. This was then shown to be wholly inadequate; and Boussingault proved conclusively that plants do not take up nitrogen gas from the air. This was subsequently denied by Ville; but investigation at the Rothamstead agricultural station by Lawes and Gilbert definitely confirmed Boussingault's results. At the same time they also proved very definitely that while grass and root crops deplete the soil of nitrogen, clover and other leguminous crops leave in the soil more nitrogen than was previously present, even when the entire, itself highly nitrogenous, leguminous crop is removed from the land. The improvement of lands for wheat production by rotation with clover had long ago become a practical maxim; but the cause was not understood until, in 1888, Hellriegel and Wilfarth announced that the variously-shaped excrescences or tubercles which had long been observed as frequently deforming the roots of legumes, are caused by the attacks of bacilli capable of absorbing the free nitrogen of the air and thus enabling the host-plant to acquire its needed supply by absorbing the richly nitrogenous matter thus accumulated in the excrescences. The minute rod-shaped organism was named *Bacillus radicicola* by Beyerinck; *Rhizobium leguminosarum,* by A. Frank, who has published an extensive treatise on the subject.[1]

Microscopic examination of the nodules shows their tissues to contain partly motile, free bacteria, partly others (bacteroids), which have assumed a quiescent condition, and are of much greater dimensions than those of the motile form. These relatively thick, and sometimes forked, forms, differing somewhat in each of the group adaptations mentioned below, constitute the bulk of the cell-contents of the nodules, and ultimately serve for the nutrition of the host-plant with nitrogen. When

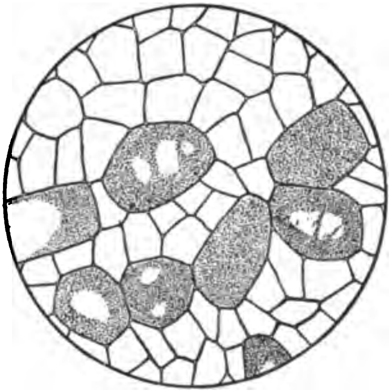

FIG. 21.—Microscopic section of cell tissue, from a nodule of Square-pod pea, showing cells filled with Rhizobia.[2]

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[1] Uber die Pilzsymbcose der Leguminosen, Berlin, 1890.

[2] Original figure from drawing by O. Butler, Asst. in Agr. Dep't Univ. of California.

the growth of the excrescence is completed, the swollen, quiescent bacteroids gradually collapse and become depleted of their nitrogenous substance; and finally the apparently empty husk remains or drops off, carrying with it the minute cocci which in the soil become active bacteria again. The nodules are thus found mainly on the actively-growing roots, and at the time when vegetation and assimilation are most active in the plant. In autumn, or when the plants are in fruit, the roots may be wholly destitute of nodules.

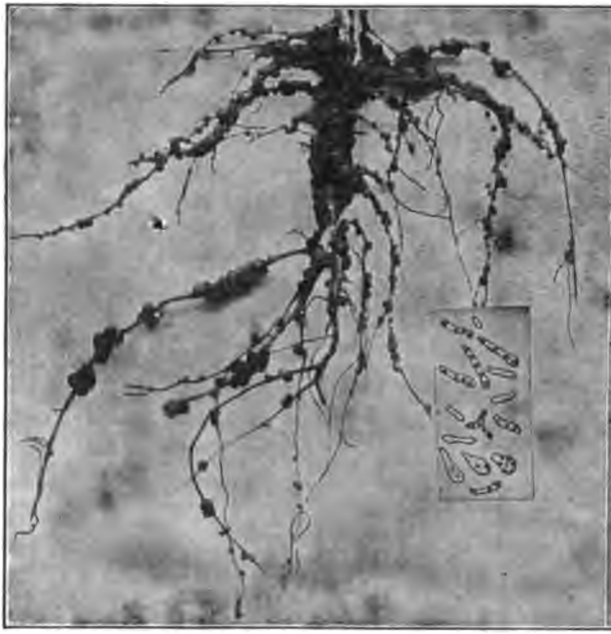

FIG. 25.—Square-pod pea.—Tetragonolobus purpureus. FIG. 26.—White Lupin.—Lupinus albus.

The adhesion of the nodules to the roots is mostly very loose, and their falling-off when the seedlings are carelessly transplanted, doubtless accounts for much of the difficulty generally found in transplanting legumes when once established.

The figures annexed show the various forms assumed by the nodules in different plants, and with them also the corresponding forms of the bacteroids of each. The latter, here shown

FIG. 22.—Common Vetch.—Vicia sativa.

FIG. 23.—Bur clover.—Medicago denticulata.

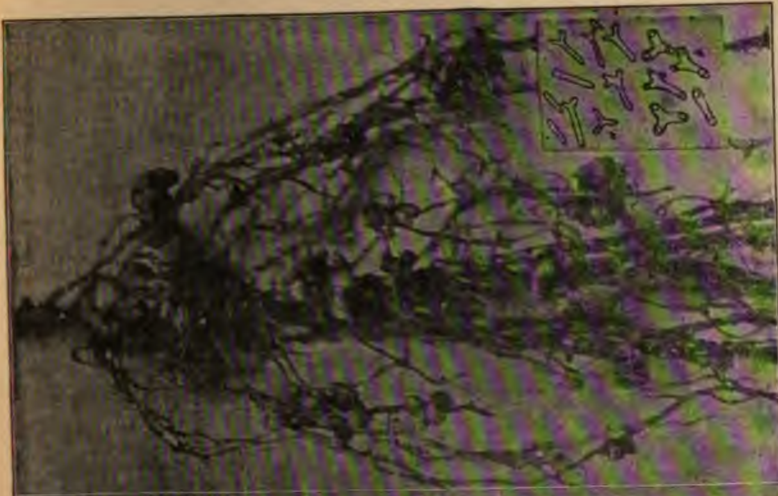

FIG. 24.—Garden pea.—Pisum sativum.

magnified about 1000 times, are taken from the inaugural dissertation of D. Brock on this subject, published at Leipzig in 1891. It appears that the forms of the bacteroids are quite as much varied as are those of the nodules they form.

Varieties of Forms.—While these bacilli seem to be normally present in most soils, it seems to be necessary that they should adapt themselves for this symbiosis[1] with each of several groups of the legumes in order to exert their most beneficial effects. In many soils there appears to exist a " neutral form, which requires about a season's time or more to adapt itself specially to the several leguminous groups so that a great advantage is gained by infecting either the seeds or the soil with the forms already adapted, when no similar plant has lately occupied the same ground. Thus the bacillus of the clover root is of little or no benefit to beans, peas or alfalfa, and the root-bacilli of each of the latter are relatively ineffectual when used to infect either of the other groups. The same is true of the bacilli of lupins and of acacias, as applied to leguminous plants of any other groups.[2]

Mode of Infection.—The infection is especially effectual when applied to the seeds before sowing; and for that purpose there may be used either the turbid water made by stirring up in it some earth of a properly infected field, or else water charged with a pure culture of the appropriate kind, commercially known under the name of nitragin, now manufactured for the purpose. Or else, the field to be sown may be infected by spreading on it broadcast, *and promptly harrowing in,* a wagon-load of earth per acre from a properly infected field. Such earth must not be allowed to dry, or to be long exposed to light.

Specially effective ("virulent") and hardy forms of such bacteria have been produced under artificial culture by Dr. Geo. T. Moore of the U. S. Department of Agriculture. These cultures can be sent by mail on cotton imbued with them, for the infection of seeds.

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[1] "Living together" beneficially; in contradistinction to parasitism, which is injurious to the host plant.

[2] It is asserted by some observers that the root bacilli producing differently-shaped excrescences upon different legumes are distinct species; but this view is not sustained by the experiments of Nobbe and Hiltner, and seems intrinsically improbable.

It is very important that the bacillus should be present in the *earliest* stages of the growth of the seedlings; otherwise the latter will undergo a longer or shorter period of starvation, unless the soil contains, or is furnished with, a sufficiency of available nitrogen to supply their immediate wants. When such a supply is very abundant, the legume crop will sometimes develop no nodules at all; but the best crops appear to be the result of a thorough infection, and abundant formation of the excrescences.

Cultural Results.—The marked results obtained in certain soils by inoculation with the legume-root bacillus are exemplified in the following table, showing results of experiments by J. F. Duggar, at the Alabama Experiment station.[1]

TABLE SHOWING INCREASE OF PRODUCTION BY SOIL INOCULATION.

PER ACRE.	TOPS.	ROOTS.	NITROGEN.	
	lbs.	lbs.	lbs.	Value.
Hairy vetch, not inoculated..........	194	387	7	$ 1.05
do. do. inoculated..............	3045	1452	106	15.90
Crimson clover not inoculated........	106	266	4.3	.65
do. do. inoculated...	4840	1452	143.7	21.25

Such marked *increases* from soil inocculation cannot of course be expected in cases where the soil has previously borne leguminous crops of similar nature and therefore already contains the root bacteria. Hence Duggar found no increase of production when inoculating for cowpea, land that had borne that crop two years before and already contained the root bacteria. In the arid region, where the almost universally calcareous soils usually bear a natural growth largely composed of various leguminous plants, inoculation is likely to be less commonly effective than in the humid region east of the Mississippi, where leguminous plants are much less generally present in the native flora.

The distinctive agricultural function of supplying nitrogen to the soils on which they grow, renders inexcusable the persistence of some writers and teachers in designating all forage plants as "grasses." Whatever excuse there may have been for this practice so long as the nitrogen-gathering function of the legumes was unknown, disappears with this discovery, and

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[1] Bull. Ala. Exp't Station, No. 96, 1898.

the misleading misnomer should be banished from agricultural publications and lectures, at the very least.

Other Nitrogen-Absorbing Bacteria.—An increase in the nitrogen-content of some soils, aside from the action of leguminous root-bacteria, has long been observed. As already stated, this increase was at first ascribed to certain green algæ often seen to develop on the soil surface; but it has now been shown that the nitrogen-gathering function belongs to at least two bacteria, one of which (*Clostridium pastorianum*) was discovered by Winogradski, the other (*Azotobacter chroococcum*) by Beyerinck, and has since been farther investigated by Koch, Kröber, Gerlach and Vogel, and last by Lipman and Hugo Fischer. According to the latter it seems likely that Azotobacter chroococcum lives in symbiosis with the green algæ, all of which, like the Azotobacter itself, develop with special luxuriance on calcareous soils.

Lipman (Rep. Agr. Exp't Station, New Jersey, 1903 and 1904) describes as *Azotobacter vinelandii* a form somewhat different from the A. chroococcus, the nitrogen-assimilating power of which he tested quite elaborately. He exposed to air pure cultures of *A. vinelandii* in nutritive solution containing the proper mineral ingredients, and glucose 20 grams per liter. 100 cub. centimeters of this solution was exposed in flasks of respectively 250, 500 and 1000 cc. content, therefore having greater surface in the larger flasks. After ten days, the amounts of nitrogen fixed were found to be respectively 1.67, 3.19 and 7.90 milligrams. When mannite solution was employed instead of glucose, a similar fixation was observed; and it was also shown that the presence of combined nitrogen in the forms of nitrates or ammonium salts discouraged the fixation by the bacillus.

It was thus clearly proved that *A. vinelandii* at least does not need symbiosis with algæ to fix atmospheric nitrogen; but experiments with mixed cultures of the above bacillus and another (designated as No, 30 by Lipman) proved that when these two co-operate the absorption of atmospheric nitrogen is nearly doubled. As it is probable that this is the case also with other soil bacteria, the importance of this source of nitrogen to plants is obvious; provided of course that the proper nutritive ingredients are present in available form. Lipman shows that among the organic nutrients, besides the sugars, glycerine and the salts of propionic and lactic acids, and probably also others of the same groups, can serve as nourishment to the nitrogen-fixing bacteria.

DISTRIBUTION OF THE HUMUS WITHIN THE SURFACE SOIL.

The uniform distribution of the humus-contents of the surface soil, as shown in sections of the same, is by no means easily accounted for. The roots from which its substance is so largely derived are not so universally distributed as to account for it; but least of all can the rapid disappearance of the leaf-fall and other vegetable offal from the surface be accounted for without some outside agencies. Of these, the action of fungous vegetation, and of insects and earthworms, are doubtless the chief ones.

Fungi.—When we examine a decaying root, we find radiating from it a zone of deeper tint, as though from a colored solution penetrating outward. But since under normal conditions humus is insoluble, this explanation cannot stand. Microscopic examination, however, reveals that the outside limit of this zone is also the limit to which the fungous fibrils concerned in the process extend; and as these fibrils are much more finely distributed and much more numerous than the roots of any plant, it is natural that the humus resulting from their decomposition should be more evenly distributed than the roots themselves.[1]

Such fungous growth is not, however, confined to dead and decaying roots only. A large number of trees and shrubs, among them pines and firs, beeches, aspen and many others, also the heaths, and woody plants associated with them, appear to depend largely for their healthy development, notably in northern latitudes, upon the co-operation ("symbiosis") of fungous fibrils that "infest" their roots, enabling them to assimilate, indirectly, the decaying organic (and inorganic) matter which would otherwise be unavailable, and at the same time converting that matter into their own substance. Fungous growths thus mediate both the decomposition and rehabilitation of the vegetable debris.

The vegetative fibrils (mycelia) of several kinds of molds are constantly present in the soil, and while consuming the dead tissue of the higher plants, spread their own substance throughout the soil mass. The same is true of the subter-

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[1] Kosticheff, Formation and Properties of Humus; in abstract Jour. Chem. Soc., 1891, p. 611.

ranean or "root" mycelia of the larger fungi, toadstools, mushrooms, which are commonly found about dead stumps and other deposits of decaying vegetable and animal offal. All these being dependent upon the presence of air for their life functions, remain within such distance from the surface as will afford adequate aeration; the depth reached depending upon the perviousness of the soil and subsoil. In the humid region this will usually be within a foot of the surface, but in the arid may reach to several feet. Ultimately these organisms contribute their substance to the store of humus in the land.

On the surface of moist soils we frequently find a copious growth of green fibrils, which may be either those of algæ, such as Oscillaria, or the early stages (prothallia) of moss vegetation. This vegetation has been credited with absorption of nitrogen from the air, thus enriching the soil; but later researches have shown this effect to be due to symbiotic bacteria (see above p. 156).

Animal Agencies.—Darwin first suggested that wherever the common earthworm (*Lumbricus*) finds the conditions of existence, it exerts a most important influence in the formation of the humous surface-soil layer; and the limitation imposed upon these conditions by the subsoil has doubtless a great deal to do with the sharp demarcation we often find between it and the surface soil. Briefly stated, the earthworm nourishes itself by swallowing, successively, portions of the surrounding earth, digesting a part of its organic matter and then ejecting the undigested earth in the form of "casts," such as may be seen by thousands on the surface of the ground during or after a rain. Darwin (The Formation of Vegetable Mold, 1881), has calculated from actual observation that in humid climates and in a ground fairly stocked with these worms, the soil thus brought up may amount to from one-tenth to two-tenths of an inch annually over the entire surface; so that in half a century the entire surface foot might have been thus worked over. Aside from the mechanical effect thus achieved in loosening the soil, and the access of air and water permitted by their burrows, the chemical effects resulting from their digestive process, and the final return of their own substance to the soil mass; also their habit of drawing after themselves into their burrows leafstalks, blades of grass and other vegetable remains, renders their work of no mean importance both from the physical and chemical point of view. The uniformity, lack of structure and loose texture of the surface soil, especially of forests, as compared with subsoil layers of corresponding thickness, is doubtless largely due to the earthworms' work. It has frequently been observed that when an unusual overflow has drowned out the earthworm population of a considerable area, the surface soil layer remains compacted, and vegetation languishes, until new immigration has restocked the soil with them. Again, the humus formed under their influence is always neutral, never acid.

Wollny (Forsch, Agr., 1890, p. 382), has shown by direct experimental cultures in boxes, with and without earthworms, surprising differences between the cultural results obtained, and this has been fully confirmed by the subsequent researches of Djemil (Ber. Physiol. Lab. Vers. Halle, 1898). In Wollny's experiments, the ratio of higher production in the presence of the worms, varied all the way from 2.6 per cent in the case of oats, 93.9 in that of rye, 135.9 in that of potatoes, 300 in that of the field pea, and 140 in that of the vetch, to 733 per cent in the case of rape. Wollny attributes these favorable effects in the main to the increased looseness, and perviousness of the soil to air, and diminished water-holding power. Djemil's results all point in the same direction; and he shows, moreover, that the allegation that the roots penetrate more deeply in the presence of the worms by following their burrows, is unfounded, the descending roots often passing close to and outside of these.

The work of earthworms is especially effective in loamy soils and in the humid regions. In the arid region, and in sandy soils generally, the life-conditions are unfavorable to the worm, and the perviousness elsewhere brought about by its labors already exists naturally in most cases. It is stated by E. T. Seton (Century Mag. for June, 1904) that the earthworm is practically non-existent in the arid region between the Rocky Mountains and the immediate Pacific coast, from Manitoba to Texas. In the Pacific coast region, however, they are abundant, and do their work effectually.

Insects of various kinds are also instrumental in producing, not only the uniform distribution of humus in the surface soil, but also the looseness of texture which we see in forest soils especially. Ants, wasps, many kinds of beetles, crickets, and particularly the larvæ of these, and of other burrowing creatures, often form considerable accumulations, due directly both to their mechanical activity, and to their excrements.

The work of *ants* is in some regions on so large a scale as to attract the attention of the most casual observer. Especially is this the case in portions of the arid region, from Texas to Montana, where at times large areas are so thickly studded with hills from three to twelve feet in diameter, and one to two feet high, that it is difficult to pass without being attacked by the insects. The "mounds" studding a large portion of the prairie country of Louisiana seem also to be due to the work of ants, although not inhabited at present.

Larger burrowing animals also assist in the task of mixing uniformly the surface soils, and aiding root-penetration, as well as, in many cases, the conservation of moisture. Seton (loc. cit.) even claims that the pocket gophers (Thomomys) in a great degree replace the activity of the earthworms in the arid region, where they, together with the voles (commonly known there as field mice), exist in great numbers. Of course the work of these animals, as well as that of the prairie dogs, ground squirrels, badgers, etc., is incompatible with cultivation. But the effects of their burrows on the native vegetation, and the indications they give of the nature of the subsoil, are eminently useful to the land-seeker.

Thus in the rolling sediment-lands of the Great Bend of the Columbia, the observer is surprised to see the "giant rye grass," usually at home in the moist lowlands, growing preferably on the crests of the ridges bordering the horizon. Examination shows that this is due to the burrowing of badgers, whereby the roots of the grass are enabled to reach moisture at all times, even in that extremely arid region.

CHAPTER X.

SOIL AND SUBSOIL (*Continued*)

THEIR RELATIONS TO VEGETATION.

Physical Effects of the Percolation of Surface Waters.—The muddy water formed by the beating of rains on the soil surface will, in penetrating the soil, carry with it the diffused colloidal clay to a certain depth into the subsoil. We should therefore expect that as a rule every subsoil will be more clayey than its surface soil; and this is found to be almost universally the case in the humid region. Subsoils are therefore almost always less percious and more retentive of moisture, as well as of plant-food substances in solution, than their surface soils, unless these are very rich in humus; and as the finest particles are usually those richest in available plant-food, it follows that subsoils will as a rule be found to contain larger supplies of the latter than the surface soil. Common experience as well as comparative analysis confirm both of these inferences so thoroughly, that it becomes unnecessary to adduce examples in this place.

On the other hand, the reverse, upward movement of moisture caused by surface evaporation tends constantly to bring any soluble salts contained in the soil mass nearer to the surface, thus increasing the stock of easily available plant-food in the surface soil. In extreme cases, especially in the arid region, this accumulation of salts may become excessive, and seriously injurious to plant growth. (See "Alkali Soils, chapters 21, 22.)

Chemical effects of Water-Percolation.—The accumulation of plant-food in the subsoil is not, however, due only to the mechanically-carried particles, but also to the ingredients carried in solution from the surface soil and redeposited in the more retentive subsoils. Especially is this true of *lime carbonate,* which is dissolved by the carbonic acid formed chiefly within the humic surface soil, and is often carried off in amounts sufficient to obstruct drain tiles by its deposition in contact with air (see chapt. 3). In the case of moderate rains, however, it is carried no farther than the subsoil, and is there redeposited, in consequence of the penetration of air, following the water, and causing the carbonic gas to diffuse upward; thus leaving the lime carbonate behind. In the majority of cases this results simply in a gradual enriching of the subsoil in this substance; while the surface soil may become so depleted as to require its artificial replacement by liming or marling. The same general process occurs to a less extent, in the case of magnesia.

Calcareous Subsoils—The fact that subsoils are more calcareous than the corresponding surface soils is often of great practical importance, in enabling the farmer to enrich his depleted surface soil in lime by subsoil plowing. The accumulation of lime carbonate in the subsoil also tends in a measure to offset the extreme heaviness sometimes resulting from the accumulation of clay.

Calcareous Subsoils and Hardpans.—When soils are very rich in lime, and rains occur in limited showers rather than continuously, the lime carbonate dissolved from the surface soil may accumulate in the subsoil so as to either form calcareous "hardpan" by the cementing of the subsoil mass; or it may accumulate and partly crystallize around certain centers and thus form white concretions, known to farmers as "white gravel." The latter is the form usually assumed in the regions of summer rains; while in the arid regions the deficient rainfall causes this substance to accumulate, and calcareous hardpan to form, at definite depths depending upon the maximum penetration of the annual rainfall; sometimes in crystalline masses of veritable limestone ("kankar" of India), or sometimes merely as crystalline incrustations loosely cementing the subsoil.

"Rawness" of Subsoils in Humid Climates.—From the greater compactness of the subsoil which is almost universal in the humid regions, the absence of humus and of the resulting formation of carbonic and humic acids, it follows that its minerals are less subject to the weathering process than are

those of the surface soil. In the farmer's parlance, the subsoil is " raw " as compared with the surface soil; it is not so suitable for plant-nutrition, and therefore must not be brought to the surface to form the seed-bed, or be incorporated with the surface soil to any considerable extent *at any one time,* if crop-nutrition is to be normal. It is only in the course of time, by exposure to atmospheric action as well as to that of the humus, and of plant roots, that it becomes properly adapted to perform the functions of the surface soil.

Soils and Subsoils in the Arid Region.—But however pronounced and important are these distinctions and differences in the humid region, they are found to be profoundly modified in the arid; where, as before stated, the formation of colloidal clay is very much diminished, so that most soils formed under arid conditions are of a sandy or pulverulent type. There is then little or no clay to be washed down into the subsoil, hence there is no compacting of the latter; the air consequently circulates freely down to the depth of many feet.

Thus one of the most important distinctions between soil and subsoil is to a great extent practically non-existent in the arid region, at least within the depths to which tillage can be made to reach; so that the limitations attached to subsoil-plowing in the countries of summer rains do not apply to the characteristic soils of the arid regions.

Even the distinction in regard to humus is here largely obliterated by the circumstance, already alluded to, that most of that substance must, in the arid regions, be derived from the decay of roots, which moreover reach to much greater depth in these soils. Hence even in the uplands of the arid region it is common to find no change of tint from the surface down to three feet, and even more. This, like the free circulation of the air in consequence of porosity, tends to render the distinction of soil and subsoil practically useless; since it disposes of the objection to " subsoiling " based upon the inert condition of the subsoil, which in humid climates so effectually interferes with the welfare of crops unless subsoiling is restricted to a fraction of an inch at a time.

These fundamental differences in the soils of the two regions are illustrated schematically in the subjoined diagram, which shows on the left the contrast between clay or clay loam soils, in which the depth of the surface soil-sample to be taken is prescribed as nine inches by the rules of the Association of Am. Official Chemists (in the writer's experience it is more nearly six inches as a rule). Alongside of the Eastern soil thus characterized is placed a typical "adobe" soil from the grounds of the California Experiment station, of which a sample showing uniform blackness to three feet depth was exhibited at the World's Fair at Chicago in 1893. At the right is a profile of the noted hop soil on the bench lands of the Russian river, Cal., in which the humus-content was determined down to twelve feet, the humus-percentage being .44% at that depth against 1.21% in the surface foot (see chapt. 8, p. 139). In this and similar soils the roots of hops reach down to as much as fourteen feet without much lateral expansion; as shown in plate No. 31 of this chapter. Similar conditions prevail in the sandy uplands, as, *e. g.*, in the wheat lands of Stanislaus county, Cal., mentioned above.

Taking the clay soils as a fair type for comparison, it would seem that the farmer in the arid region owns from three to four farms, one above another, as compared with the same acreage in the Eastern states.

Subsoils and Deep-plowing in the Arid Region.—Up to the present time this advantage is but little appreciated and acted upon by the farmers of the arid region. They still instinctively cling to the practice taught them by their fathers, and which is still promulgated as the only correct practice, in most books on agriculture. There are of course in the arid as well as in the humid region, cases in which deep plowing is inadvisable; viz, that of marsh or swamp lands, as well as sometimes in very sandy, porous soils, the cultural value of which often depends essentially upon the presence of a somewhat consolidated, and more retentive subsoil, which should not be broken up. But in most soils not of extreme physical character, it is in the arid region not only permissible, but eminently advisable to plow, for preparation, as deeply as circumstances permit, in order to facilitate the penetration of the roots beyond the reach of harm from the summer's drought; while for the same reason, subsequent cultivation should be to a moderate depth only, for the better conservation of moisture, and the formation of a protective surface mulch (see chapter 13).

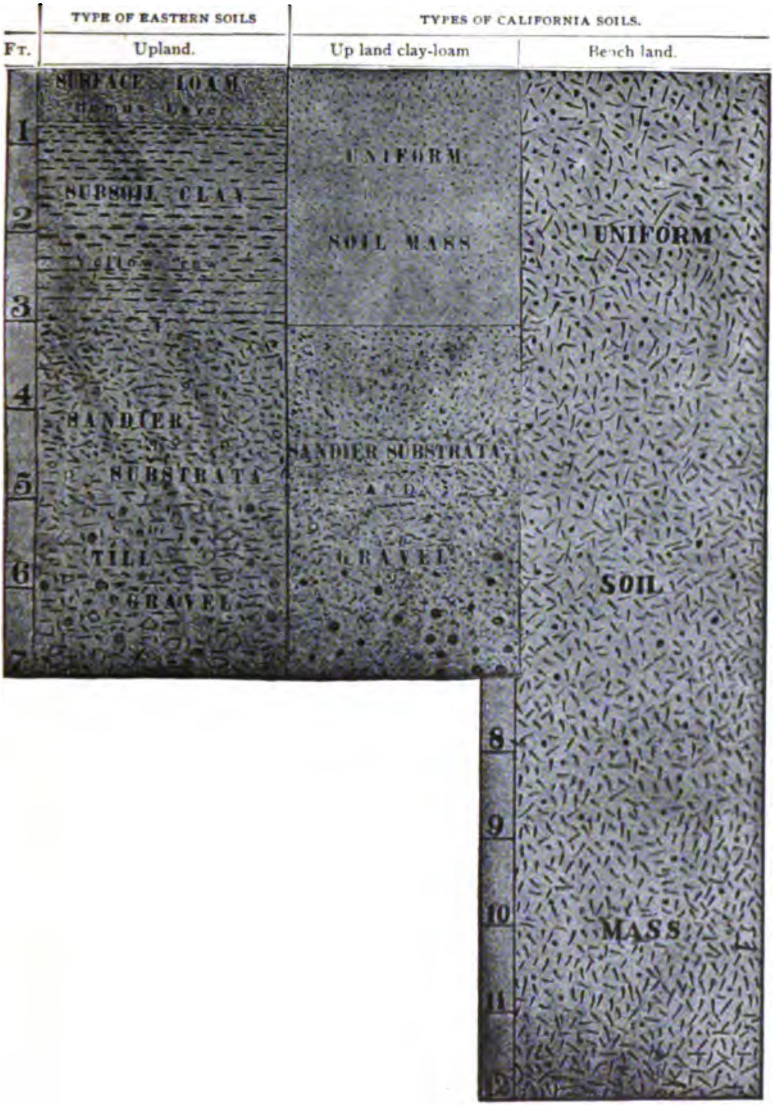

FIG. 27.—Soil Profiles illustrating differences in Soils of Humid and Arid Region.

It must not be forgotten that there are in the lowlands of the arid region (river swamps or tules, seacoast marshes, etc.,) soils in which surface soil and subsoil are differentiated as fully as in the humid countries; at least so long as they have not been fully drained for a considerable length of time. In swamp areas that have been elevated above the reach of overflow or shallow bottom-water by geological agencies, even the heavy swamp clays are fully aerated down to great depths, and roots penetrate accordingly.

Examples of Plant-growth on Arid Subsoils.—The fact that in the arid region the surface-soil conditions reach to so much greater depths than in the East and in Europe, is so important for farming practice in that region that experimental evidence of the same should not be withheld. Of such, some cases well established as typical of California experience are therefore cited.

It is well known that in the Sierra Nevada of California the placer mines of the Foothills, worked in the early times, have long disappeared from sight, having been quickly covered by a growth of the bull pine (*P. ponderosa*). Much of this timber growth has for a number of years past been of sufficient size to be used for timbering in mines, and a second young forest is springing up on what was originally the red earth of the placer mines, which appears to the eye as hopelessly barren as the sands of the desert. In this same red sandy earth not unfrequently cellars and house foundations are dug, and the material removed, even to the depth of eight feet, is fearlessly put on the garden and there serves as a new soil, on which vegetables and small fruits grow, the first year, as well as ever. In preparing such land for irrigation by leveling or terracing no heed is taken of the surface soil as against the subsoil, even where the latter must be removed to the depth of several feet, so long as a sufficient depth of soil material remains above the bedrock.

The same is generally true of the benchlands; the irrigator levels, slopes or terraces his land for irrigation with no thought of discrimination between soil and subsoil, and the cultural result as a rule justifies his apparent carelessness. It is only where from special causes a consolidated or hardpan subsoil is brought to the surface, that the land when leveled shows "spotted" crops. Such is the case in some of the "hog-wallow" areas of the San Joaquin valley of California, and in some cases where by long cultivation and plowing to the same depth, a compact soil-layer or plowsole has been formed, and the land is then leveled for the introduction of irrigation. In these cases a section of the soil mass will usually show a marked difference in color and texture. But, as a rule, in taking soil samples, no noticeable difference can be perceived between the first and the second, and oftentimes as far down as the third and fourth foot. The extraordinary root-penetration of trees, shrubs and taprooted herbs, whose fibrous feeding-roots are found deep in the subsoil and are sometimes wholly absent from the surface soil, fully corroborate the conclusion reached by the eye. The roots of grape vines have been found by the writer at the depth of twenty-two feet below the surface, in a gravelly clay loam varying but little the entire distance. In a similarly uniform and pervious material, the loess of Nebraska, Aughey[1] reports the roots of the native Shepherdia to have been found at the depth of fifty feet.

Resistance to Drought.—These peculiarities of the soils of the arid region explain without any resort to violent hypotheses, the fact that many culture plants which in the regions of summer rains are found to be dependent upon frequent and abundant rainfall, will in California, and in the country west of the Rocky Mountains generally, thrive and complete their growth and fruiting during periods of four to six months of practically absolute cessation of rainfall; when east of the Mississippi a similar cessation for as many *weeks* will ruin the crops, if not kill the plants. In continental Europe, in 1892, a six weeks' drought caused almost all the fruit crops to drop from the trees, and many trees failed to revive the next season; while at the very same time, the same deciduous fruits gave a bountiful crop in California, during the prevalence of the usual five or six months' drought. This was without irrigation, or any aid beyond careful and thorough surface tillage following the cessation of rains in April or May, so as to leave the soil to the depth of five or six inches in a condition of looseness perfectly adapted to the prevention of evaporation from the moist subsoil, and of the conduction of the excessive heat of the summer sun. This surface mulch will contain practically no feeding-roots, the paralysis or death of which by heat and drought would influence sensibly the welfare of the growing plant.

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[1] See Merrill, Rocks and Rockweathering.

Root-system in the Humid Region.—It is quite otherwise where a dense subsoil not only obstructs mechanically the deep penetration of any but the strongest roots, but at the same time is itself too inert to provide sufficiently abundant nourishment apart from the surface soil, which is there the portion containing, alongside of humus, the bulk of the available plant-food, and in which alone the processes of absorption and nutrition find the proper conditions; such as access of air and the ready and minute penetration of even the most delicate rootlets and root-hairs. The largest and most active portion of the root-system being thus accumulated in the surface soil, it follows that unless the latter is constantly kept in a fair condition of moistness, the plant must suffer material injury very quickly; hence the often fatal effects of even a few weeks' drought. The same occurs in the arid region when often-repeated shallow plowing has resulted in the formation of a "plow-sole" which prevents the deep penetration of roots; when a

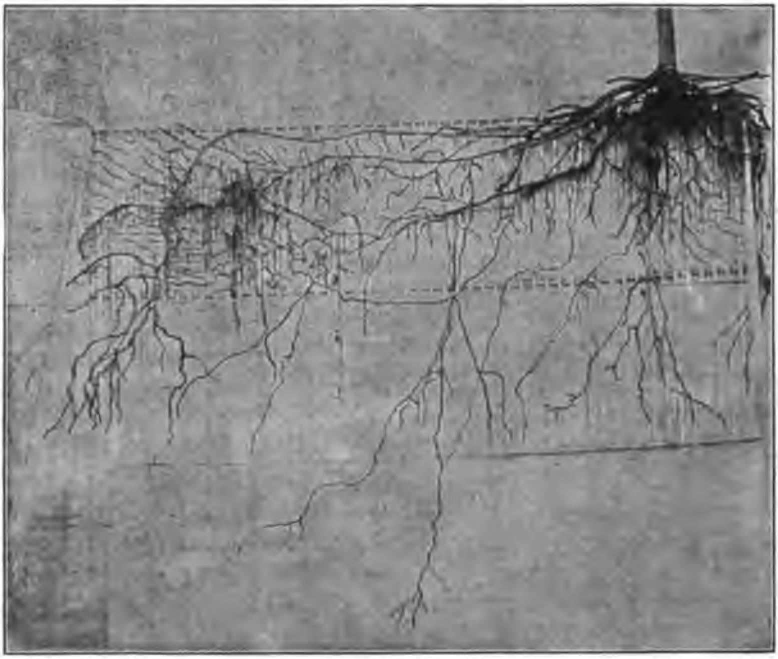

FIG. 28.—Root of an Eastern (Wisconsin) Fruit Tree. (Photograph by Prof F. H. King.)

hot "norther" will often in a short time not only dry the plowed soil, but will heat it to such extent as to actually bake the roots it harbors. Under the same weather-conditions an adjoining field, properly plowed, may almost wholly escape injury.

Comparison of root development in the arid and humid regions.—Figures 28, 29 given here show the differences as actually seen in the case of fruit trees as grown in Wisconsin and California, respectively, both in the absence of artificial water-supply.

FIG. 29.—Prune Tree on Peach Root, at Niles, Cal.

Adaptation of humid species to arid conditions.—Figures, in No. 30, show the root systems respectively of the riverside grape (*Vitis riparia*) as grown in the Mississippi Valley states, and the natural development as found in the Rock grape of

Missouri and also in the wild grape vine of California. It will be noted at once that the latter directs its cord-like roots almost vertically from the first, until it reaches a depth varying from 12 to 18 inches, where it begins to branch more freely, but still with a strong downward tendency in all. The roots of the riverside grape, on the contrary, tend to spread almost horizontally, branching freely at the depth of a few inches and manifestly deriving its supply both of plant-food and moisture mainly from the surface soil. It is curious to observe the behavior of this vine when cuttings are planted in California vineyards as a resistant grafting-stock. Its first roots are sent out horizontally, very much as is its habit in the East, so long as the soil moisture is maintained near the surface. But as the season advances, the more superficial rootlets are first thrown out of action by the advancing dryness and heat of the surface soil, and many finally die the first year.

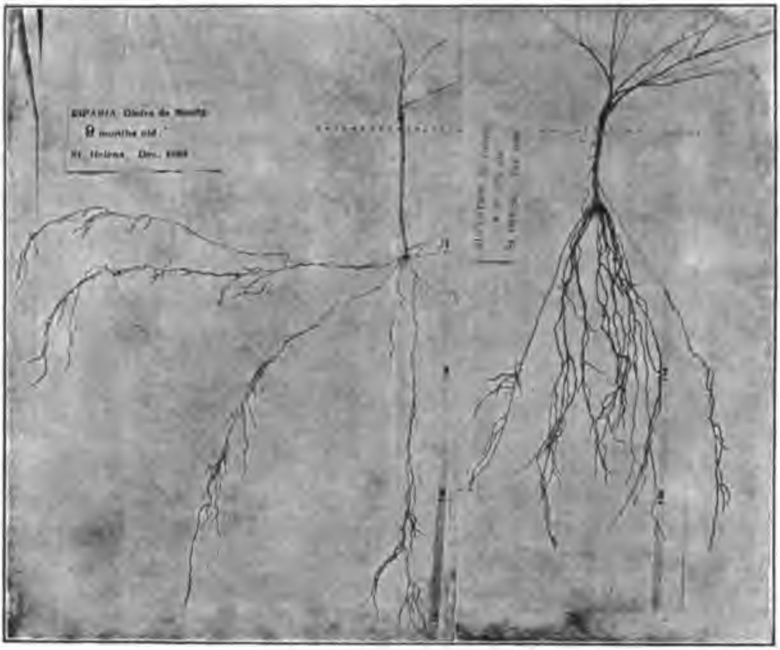

Fig. 30.—Root Growth of Resistant Grape Vines.

Not unfrequently the entire root system developed by the uppermost bud perishes; but usually its main roots soon begin to recede from the threatening drought and heat of the surface, curving, or branching downward in the direction of the moisture supply, and without detriment to their nutrition because of the practical identity of the surface soil and subsoil. As the portions of the roots near the surface thicken and mature, their corky rind soon prevents their being injured by the arid conditions to which they are subjected; while the root-ends, finding congenial conditions of nutriment and aeration in the moist depths, develop without difficulty as they would in their humid home. Practically the same process of adaptation takes place in every one of the trees, shrubs, or perennials belonging to the humid climates, until their root system has assumed nearly the habit of the corresponding native vegetation.

The photograph of the roots of a hop plant, grown on bench lands of the Sacramento river, shows the roots extending to 8 feet depth, but where broken off the main root is still nearly two millimeters in thickness, proving that it penetrated at least two feet beyond the depth shown in figure 31.

In the case of native annuals, either the duration of their vegetation is extremely short, ending with or shortly after the cessation of rains; or else their tap roots descend so low, and the nutritive rootlets are developed at such depth, as to be beyond reach of the summer's heat and drought. For while it is true that rootlets immersed in air-dry soil may absorb plant-food, this absorption is very slow and can only be auxiliary to the main root system which, instead of terminating in the surface soil as in the humid region, will be found to begin to branch off at depths of 15 and 18 inches, and may then in sandy lands descend to from 4 to 7 feet even in the case of annual fibrous-rooted plants like wheat and barley.[1] In the case of maize the roots of a late-planted crop may sometimes be found descending along the walls of the sun-cracks in heavy clay land

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[1] Shaler (Origin and Nature of Soils; 12th Rept. U. S. Geol. Survey, p. 311) says: "Annual plants cannot in their brief period of growth push their roots more than six to twelve inches below their root-crowns"—a generalization measurably true for the humid region only. According to F. J. Alway, the roots of cereals penetrate to 5-7 feet in Saskatchewan, also.

Fig. 31.—Hop Root from Sacramento Bench-land.

poorly cultivated; and it frequently matures a crop without the aid of a single shower after planting. See figures 33, 34.

The annexed plate (No. 32) shows the main roots of two native perennial weeds of California, the goosefoot (*Chenopodium californicum*) and the figwort (*Scrophularia californica*), common on the lower slopes of the coast ranges. The soil was a heavy clay loam or "black adobe" resulting from the weathering of the clay shale bedrock, fragments of which are so abundantly intermixed with the substrata that excavation of the roots became very difficult. Yet the main root of the goosefoot went down below the depth of eleven feet.

The main root of the figwort, also, was followed below the depth of ten feet without reaching the extreme end. This proves clearly that the great penetration of the goosefoot was not, as might be supposed, due to its bulbous root. Yet such thickening of the root just below the crown is a rather common feature in arid-region plants, and can here be noted even in the figwort, within whose botanical relationship bulbous roots are almost unknown.

Any one accustomed to the cornfields of the Middle West, where in the after-cultivation of maize it is necessary to restrict very carefully the depth of tillage to avoid bringing up a mat of white, fibrous roots, will be at once impressed with the remarkable adaptability of maize to different climatic conditions, as exhibited in such cases and shown in figures 33, 34. In southern California, in the deep mesa or bench soils, corn stalks so tall that a man standing on horseback can barely reach the tassel, and with two or three large ears, are quite commonly grown under similar rainfall-conditions.

Importance of proper Substrata in the Arid Region.—The paramount need of deep penetration of roots in the arid region renders the substrata below the range of what is usually understood by subsoil in the humid climates, of exceptional importance. A good farmer anywhere will examine the subsoil to the depth of two feet before investing in land; but more than this is necessary in the arid region, where the surface soil is often almost thrown out of action during the greater part of the growing season, while the needful moisture and nourishment must be wholly drawn from the subsoil and substrata;

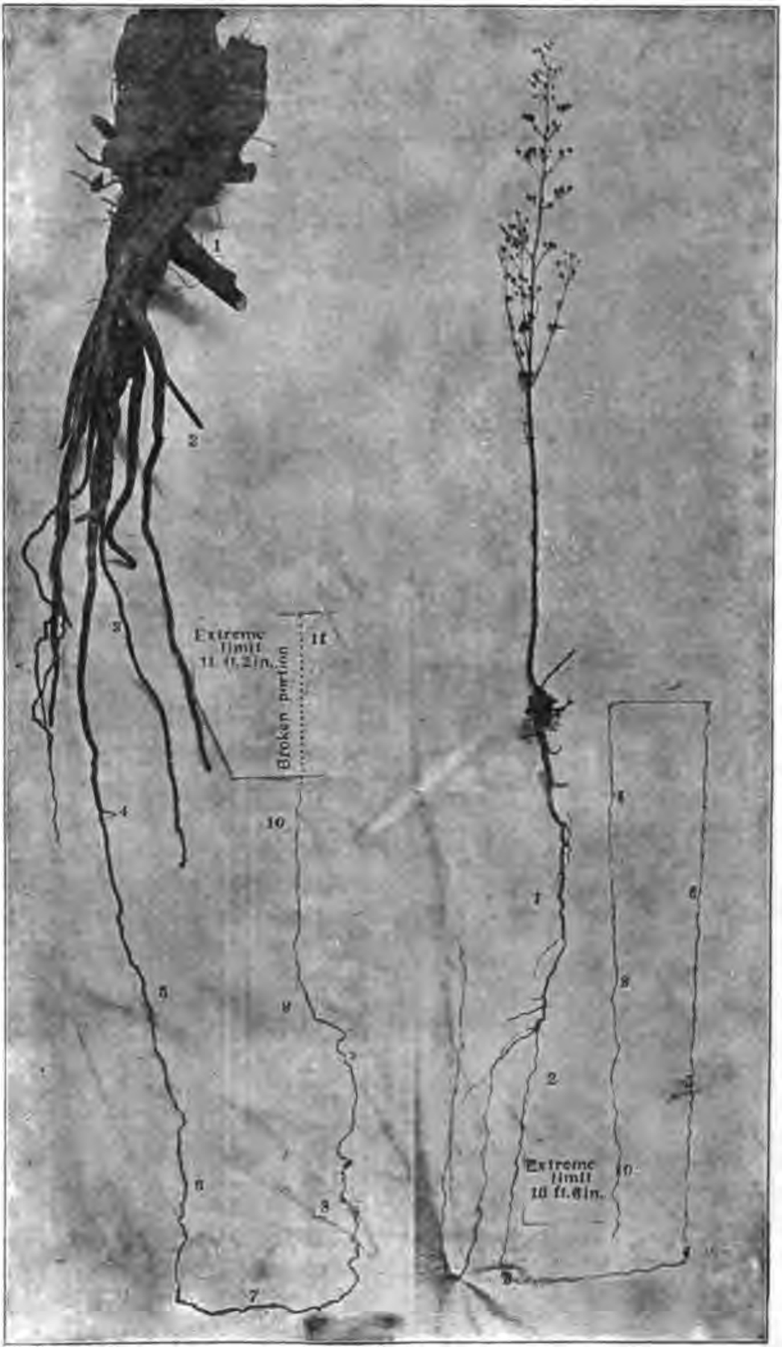

FIG. 32. – Deep-Rooting of Native California Goosefoot and Figwort.

Fig. 33.—Kentucky Maize, grown in region of Summer Rains. (Photography by A. M. Peter.)

FIG. 34.—California Maize, Grown Without Rain or Irrigation.

an examination of which should therefore precede every purchase of land, or planting of crops.

Such examinations are most quickly made by means of a probe consisting of a pointed, square steel rod five or six feet long, provided at one end with a loop for the insertion of a cross-handle like that of a carpenter's auger. The handle being grasped with both hands, the probe is forced into the soil with a slight reciprocating motion, by the weight of the operator; who soon learns how to interpret the varying kinds of resistance, and on withdrawing the probe carefully will generally be able to determine if bottom water has been reached. Should this easy method of examination not convey all the needful information, the posthole auger may be resorted to; and it is desirable that extra (three-foot) rods or gaspipe joints be provided for the purpose of lengthening the probe or auger, when necessary, to nine or twelve feet. It will rarely be necessary to go to the trouble of digging a pit for such examinations; but even this is to be recommended rather than "buying a cat in a bag" in the guise of an unexplored subsoil.

Faulty Substrata.—A number of examples of "faulty lands," *i. e.,* such as are underlaid by faulty substrata, are given in the annexed diagram Fig. 35; the examples being taken from California localities because of their having been most thoroughly investigated. Similar cases, as well as others not here illustrated, of course occur more or less all over the world.

No. 1 shows a case which, though at first sight an aggravated one of a rocky substratum, is in reality that of some of the best fruit lands in the State. The limited surface-soil is very rich, and is directly derived (as a "sedentary" soil) from the underlying bedrock slate. But this it will be noted stands *on edge,* and the roots of trees and vines wedge their way along the cleavage planes of the slate to considerable depth, deriving from them both nourishment and moisture. Under similar conditions the California laurel, usually found on the banks of streams, grows on the summits of rocky ridges in the Coast Ranges.

The case of No. 2 is quite otherwise. Here the shale lies horizontally, and though much softer than the slate of the first column, obstinately resists the penetration of roots; so that the land, though fairly provided with plant-food, is almost wholly

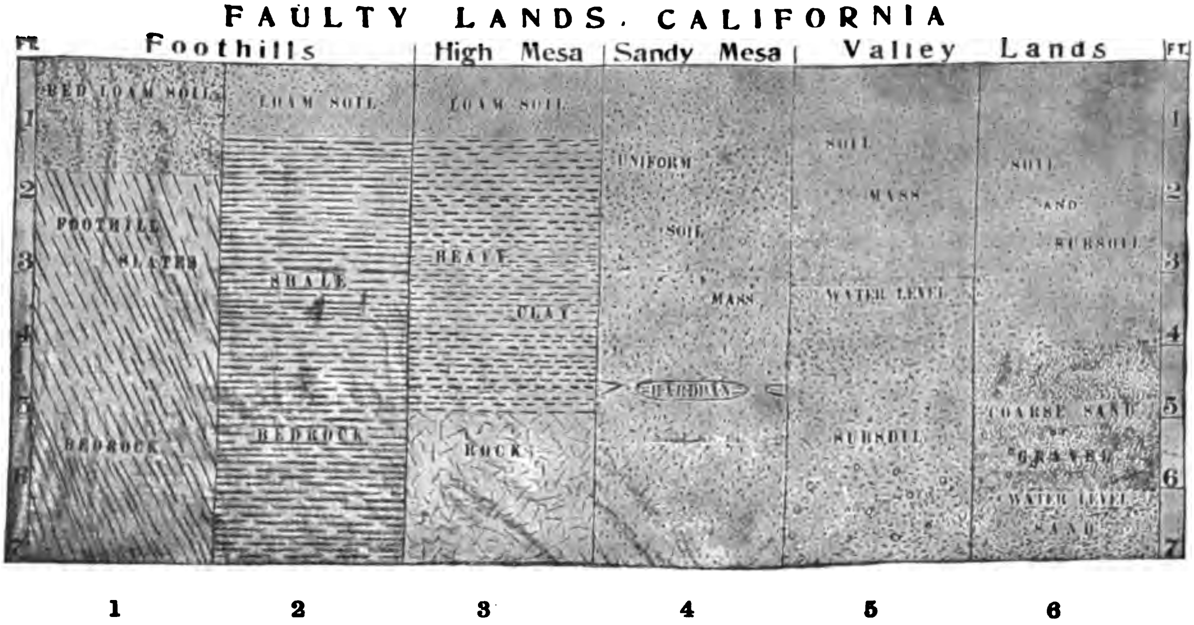

FIG. 35.—Faulty Lands, California.

useless for cultivation. It is naturally covered with low, stunted shrubs or chaparral; only here and there, where a cleft has been caused by earthquakes or subsidence, a large pine tree indicates that nourishment and moisture exists within the refractory clay stratum, and suggests blasting as a means of rendering the land fit for trees at least.

No. 3 is a case similar to that of No. 2, only there is here a dense unstratified mass of red clay, of good native fertility. It is here that the expedient of blasting the tree holes with dynamite was first successfully employed, in central California. For lack of this, extensive tracts of similar land in southern California, planted to orchards, have completely failed of useful results after three years of culture.

No. 4 shows a typical case of calcareous hardpan obstructing the penetration of roots, even though usually interrupted at intervals, because of the formation occurring mostly in swales, along which the sheets lie more or less continuously. Here also, blasting will generally permit the successful growth of trees and vines, whose roots frequently will, in time, wholly disintegrate the hardpan and thus render the land fit for field cultures. The depth at which such hardpan is formed usually depends upon the depth to which the annual rainfall penetrates. (See below, page 183).

Nos. 4, 5, and 6 all illustrate cases of intrinsically fertile, very deep soils, shallowed by obstructions which in the case of No. 4 are hardpan sheets, while in No. 5 the intervention of bottom water limits root penetration, hence restricts the use of the land to relatively shallow-rooted crops, and the use of only a few feet of the profusely fertile soil. Such is the case where bottom water has been allowed to rise too high, through the use of leaky irrigation ditches.

No. 6 illustrates a case not uncommon in sedimentary lands, where bottom water is quite within reach of most plants, but is prevented from being utilized by the intervention of layers of coarse sand or gravel, through which the water will not rise; and the roots, while they would be able to penetrate, are not near enough to feel the presence of water underneath and therefore spread on the surface of the gravel, suffering from drought within easy reach of abundance of water. The "going-back" of large portions of orange orchards in the San Ber-

FIG. 36.—Almond Tree on Hardpan. Paso Robles Substation, Cal.

nardino Valley of California has been thus brought about; and unfortunately this state of things is almost beyond the possibility of remedy.

Injury from Impervious Substrata.—The injurious effects of a difficultly penetrable subsoil have already been discussed and are selfevident. When the substratum is a dense clay, the rise of moisture from below being very slow, it can easily happen that the roots cannot penetrate deep enough in time for the coming of the dry season, and that thus the crop will suffer. The case will be still worse when hardpan cemented by lime or silex limits root-penetration, as well as proper drainage. In such cases the culture of field crops often becomes impracticable, even with irrigation, as its frequent repetition, besides being costly, can rarely be commanded. In the case of trees, the limitation of root-penetration results in the spreading-out of the roots on the surface of the impenetrable layer; as shown in figure 36, which exhibits a root-development that would be quite normal in the regions of summer rains, but is wholly abnormal in the arid region, and results in the unprofitableness or death of the trees. It has often been attempted in such cases to plant trees in large holes dug deep into the subsoil and refilled with surface earth and manure. All such attempts result in failure, if only because the excavation inevitably fills with water, which will soak away but very slowly into the dense substrata, and will thus injure or drown out the roots. Besides, the latter will remain bunched in the loose earth, and will thus be unable to draw either moisture or nourishment from the surrounding land. It is absolutely necessary to remedy this by loosening the substrata, if success is to be attained.

Shattering of Dense Substrata by Dynamite.—The permanent loosening of dense substrata is best accomplished by moderate charges (½ to ¾ pounds) of "No. 2" dynamite at a sufficient depth (3 to 5 feet). The shattering effect of the explosive will be sensible to the depth of eight feet or more, and will fissure the clay or hardpan to a corresponding extent sidewise. If properly proportioned the charge will hardly disturb the surface; but if this be desired, from 1½to 2½ pounds of black powder placed above the dynamite will throw out sufficient earth to plant the tree without farther digging. Where labor is high-priced this proves the cheapest as well as the best way to prepare such ground for tree planting; and it has often been found that in the course of time, the loosening begun by the powder has extended through the mass of the land so as to permit the roots to utilize it fully, and even to permit, in after years, of the planting of field crops where formerly they would not succeed.

Leachy Substrata.—While we may thus overcome the disadvantages of a dense subsoil or hardpan, there is another difficulty not uncommonly met with in alluvial lands, which cannot be so readily remedied. It is the occurrence, at from two to six feet depth, of coarse sand or gravel, through which capillary moisture will not ascend, but through which irrigation water will waste rapidly, leaving the overlying soil dry. Then unless very frequent irrigation can be given, the crop will suffer from drought, unless indeed the gravel itself is filled with bottom water upon which the root-ends can draw.

This case is a common one in the larger valleys of the arid region, and in time of unusual drought the sloughs originally existing, but since filled up, will be clearly outlined by the dying crops, while outside of the old channels there may be no suffering.

"Going-back" of Orchards. On such land as this, and on such as has a shallow soil underlaid by an impervious subsoil, trees will often grow finely for three to five years; then suddenly languish, or turn yellow and die, as the demand of their larger growth exceeds what moisture or plant-food the shallow soil and subsoil can supply. Enormous losses have arisen from this cause in many portions of the arid region, but more especially in California, owing to the implicit confidence reposed even by old settlers, and still more by newcomers, in the excellence of the lands, as illustrated by farms perhaps a short distance away, but differently situated with respect to the country drainage and the geological formations. All such disappointments could have been avoided by an intelligent observation of the substrata, either by probing or digging. Important as is such preliminary examination in the region of summer rains, it is a *vitally* needful precaution in the arid

region, where the margin between adequate and inadequate depth of soil and moisture-supply is much smaller.

When farmers note such distress in the orchard, the first idea usually is that fertilization is needed. This in the almost universally very rich lands of the arid region is rarely the case until after many years of exhaustive cultivation, and is scarcely ever of more than passing benefit in such cases. The first suggestion should always be an *examination of the substrata,* and especially of the deeper roots; in the diseased or thirsty condition of which the cause of the "die-back" or yellowing will commonly be found. Of course no amount of fertilization can permanently remedy such a state of things, arising from impervious substrata, coarse gravel, or shallow bottom water.

Hardpan.—By "hardpan" is understood a dense and more or less hardened layer in the subsoil, which obstructs the penetration of both roots and water, thus materially limiting the range of the former both for plant-food and moisture, and giving rise to the disadvantages following such limitation, as described in the case of dense subsoils. The hardpans proper differ from the latter, however, in being usually of limited thickness only; the direct consequence of their mode of formation, which is not direct deposition by water or other agencies, but the infiltration of cementing solutions into a pre-existing material originally quite similar to that of the surface soil. Such solutions usually come from above, more rarely from below, and are of very various composition. The solutions of lime carbonate in carbonated water have already been referred to in this connection; as has also the fact that corresponding solutions of silica, associated more or less with other products of rock decomposition (see chapters 2 and 4) are constantly circulating in soils. The surface soil being the portion where rock-weathering and other soil-forming processes are most active, these solutions are chiefly formed there; and according as their descent into the substrata is unchecked, or is liable to be arrested at some particular level, whether by pre-existing close-grained layers or by the cessation of rains, the subsequent penetration of air, and evaporation of the water alone by shallow-rooted plants, may cause the accumulation of the dissolved matter at a certain level, year after year. Finally there is formed a subsoil-mass more or less firmly cemented by the dissolved matters, sometimes to the extent of stony hardness (lime carbonate in the arid regions, kankar of India), more usually soft enough to be penetrated by the pick or grubbing hoe, and sometimes by the stronger roots of certain plants; but resisting both the penetration and the assimilation of plant food by the more delicate feeding roots.

Nature of the Cements.—The nature of the cements that serve to consolidate the hardpan mass is substantially the same as those already mentioned in the discussion of sandstones (chapt. 4, p. 55); with the addition of those formed, usually in connection with siliceous solutions, by the acids of the humus group. The latter class of hardpans is especially conspicuous in the case of swampy ground and damp forests, where " moorbedpan " and reddish " ortstein " (the latter particularly developed in the forests of northern Europe, where it has been studied in detail by Müller and Tuxen [1], are characteristic. The latter gives for a characteristic sample of the reddish hardpan underlying a beech forest in Denmark a content of from 2.20 to 4.40% of ulmic compounds, and shows that the color is due to these and not, as had been supposed, to ferric oxid, which is present only in minute quantities.

Bog ore, Moorbedpan, Ortstein.—It is otherwise with moorbedpan, which often consists of a mass of bog iron ore permeated or less with humous substances, which impart to it the dark brown tint so often seen also in the " black gravel " spots of badly-drained land. On the whole, however, ferric cements are much less frequently found in hardpans than in sandstones formed above ground.

Clay substance washed from the surface into the subsoil by rains (chapter 10, p. 161) always helps materially to render the hardpan impervious when afterwards cemented, a much smaller proportion of the cementing material sufficing in that case to form a solid layer. In such cases however the cement is rarely of a calcareous nature, since lime prevents the diffusion and washing-down of the clay. It is mostly siliceous or zeolitic; if the former, acid will have little or no effect upon the solidity of the hardpan; while if zeolitic, acid will pretty

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[1] See " Studien über die natürlichen Humusformen," by Dr. P. E. Müller.

promptly disintegrate it. The presence of humus acids in the cements, if not apparent to the eye, is readily demonstrated by immersing the hardpan fragment in ammonia water or a weak solution of caustic soda; when if humus acids are the main cementing substance the fragment will fall to crumbs, or be softened to an extent corresponding to the amount of the humus present. Calcareous hardpan is, of course, readily recognized by its quick disintegration by dilute acid, with evolution of carbonic gas.

In "alkali" soils containing sodic carbonate ("black alkali") there is commonly found at the depth of two or three feet an exceedingly refractory hardpan resulting from the accumulation of puddled clay (see above chapt. 4, p. 62) in the subsoil, or sometimes even on the surface of depressed spots. This hardpan, easily destroyed by the use of gypsum and water, is described more in detail in chapter 22, on alkali soils; it blues red litmus paper instantly.

The Causes of Hardpan.—The recognition of the *cause* of hardpan is of considerable importance to the farmer, because of the influence of the nature of the cement and the causes of its formation upon the possibility and methods of its destruction, for the improvement of the land.

It may be said in general that inasmuch as the cause of the formation of hardpan is a stoppage of the water in its downward penetration, the re-establishment of that penetration will tend to prevent additional induration; moreover, experience proves that whenever this is accomplished even locally, as around a fruit tree in an orchard, the hardpan gradually softens and disappears before the frequent changes in moisture-conditions and the attack of roots. The use of dynamite for this purpose in California has already been referred to; it seems to be the only resort when the hardpan lies at a considerable depth. When it is within reach of the plow, it may be turned up on the surface by the aid of a subsoiler and will then gradually disintegrate under the influence of air, rain and sun. But when the hardpan is of the nature of moorbedpan, containing much humic acid and perhaps underlaid by bog iron ore, the use of lime on the land is indicated, and will in the course of time destroy the hardpan layer. This is the more desirable as in such cases the surface soil is usually completely leached of its lime content, and is consequently extremely unthrifty.

Woodlands of northern countries bearing beech and oak are especially apt to be benefited by the action of lime on the "raw," acid humous soil and underlying hardpan, which is commonly underlaid by a leaden-blue sandy subsoil ("Bleisand" of the Germans, "Podzol" of the Russians) colored brown by earth humates and mostly too moist in its natural condition to permit of adequate aeration. These soils are usually of but moderate fertility, and are best suited to forest growth unless somewhat expensive methods of improvement can be put into practice.

"Plowsole."—An artificial hardpan is very commonly formed under the practice of plowing to the same depth for many consecutive years. The consolidated layer thus created by the action of the plow (hence known as plowsole) acts precisely like a natural hardpan, and is sometimes the cause of the formation of a cemented subsoil crust simulating the natural product. This is most apt to occur in clayey lands, and greatly increases the difficulty of working them, while detracting materially from the higher productiveness commonly attributed to them as compared with sandy lands. Of course it is perfectly easy to prevent this trouble by plowing to different depths in consecutive years, and running a subsoil plow from time to time. In this case, also, lime will generally be very useful and be found to aid materially in the disintegration of the "plowsole."

It is hardly necessary to insist farther upon the need of the examination of land to be occupied, for the existence of hardpan or other faulty subsoil, which may totally defeat for the time being the farmer's efforts, or make him lose his investment in plantations after a few years. Probing by means of the steel rod described above (p. 177) or boring with a posthole auger; or finally, if necessary, digging a pit to the proper depth (from four to six feet in the arid region), should precede every purchase of new or unexplored agricultural land.

Marly Substrata.—Among the causes of failure occasionally found in the case of the "going-back" of orchards, is the occurrence of strongly calcareous or marly substrata, at depths which in the humid region would not be reached by the roots, but in the course of a few years are inevitably penetrated by the roots of trees in the arid region. Then there appears a stunting of the growth, and sometimes a yellowing of leaves, or chlorosis, due to the influence of excessive calcareousness at the depth of four or five feet. For this of course there is no remedy except the planting of crops which, like the mulberry, Texas grapes, Chicasaw plum and others, are at home on such lands; which in the Eastern states are naturally occupied by the crab apple, honey locust and wild plums.

CHAPTER XI.

THE WATER OF SOILS.

HYGROSCOPIC AND CAPILLARY MOISTURE.

When it is remembered that from 65 to over 90% of the fresh substance of plants consists of water, the importance of an adequate and regular supply of the same to growing plants is readily understood. But it seems desirable, before discussing the relations of water to the soil and to plant life, to consider first the physical peculiarities which distinguish it from nearly all other substances known. That it is colorless, tasteless, inodorous, and also chemically neutral, alone constitutes a group of properties scarcely found in any other fluid. But its special adaptation to its functions in relation to vegetable and animal life are much more fundamental, as is shown in the table of its physical constants as compared with other well-known substances, given below.

PHYSICAL FACTORS OF WATER COMPARED WITH OTHER SUBSTANCES (PER UNIT WEIGHT).

Capillary ascent in glass tubes of one mm. diameter.		Specific Heats.		Heat of Evaporation.	
Water	14 mm.	Water	1.000	Water at 20° C.	.613 Cal.
Alcohol	6 mm.	Ice	.502	" " 100° C.	.637 "
Olive oil	1 mm.	Steam	.475	Alcohol	.209 "
		Clay, Glass	.180–.200	Spirits of Turpentine	67 "
Heat Relations.		Charcoal	.241		
Density.		Wood	.032		
		Gold, Lead	.032–.031		
		Zinc	.096		
Water at 0° C. (freezing pt.)	.99988	Steel	.119		
Water at 4° (Maximum density)	1.00000	**Heat of fusion.**			
Water at 15° C. (ordinary temperature)	.990	Water (Ice)	80 Cal.		
Ice at 0° (freezing pt.)	.92800	Metals	5–28 "		
		Salts, (incl. silicates)	40–63 "		

Summarizing the meaning of the data given in the above table with respect to organic life, we see, first, that water rises higher both in the soil and in the tissues of the plant than any other liquid. Second, that as its density decreases in cooling after a certain point is reached, it freezes at the *surface* instead of at the *bottom,* as other liquids do; and as solid water (ice) is lighter than fluid water, ice stays at the surface and is readily melted when spring comes. Third, since its temperature changes more slowly than that of any other liquid, it serves to prevent injuriously rapid changes of temperature in plants and animals as well as in soils. Its high "heat of fusion" also serves to prevent quick freezing of plant and animal tissues, so that the brief prevalence of a low temperature may be more readily borne. Finally, the large amount of heat absorbed in evaporation of water serves to keep both plants and animals cool under excessive external temperatures which would otherwise quickly destroy life.

Capillarity or Surface Tension.—In this table it will be noted, first, that water rises higher in fine ("capillary") or hair tubes than the other fluids mentioned, which fairly represent all others. No other fluid approaches water in the height to which it will rise[1] in either soils or plant tissues. Were its capillary factor no higher than, *e. g.*, that of oil or alcohol, trees could not grow as tall as we find them, and the water supply from the substrata, and all the movements of water in the soil, and hence plant growth, would be similarly retarded. It is easy to verify these differences by immersing a cylinder of clay soil (or a cotton wick) in water on the one hand, and in oil or alcohol on the other. Notwithstanding the greater fluidity of alcohol as compared with water, the latter will be found to fill the porous mass much more quickly.

The smaller the diameter of the tube, the higher will the water rise in it, and the greater will be the curvature of its upper surface, to which the rise is sensibly proportional. But in the case of liquids which do not "wet" the walls of the tube (as in that of mercury and glass), the curve (meniscus) is convex, instead of concave, and the liquid is depressed instead of rising.

It is in its *relations to heat,* however, that water is specially distinguished from other substances; and these differences are

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[1] Excepting only the water-solutions of certain salts, among which common salt, kainit and nitrate of soda are of agricultural interest. Common salt may increase the capillary rise to the extent of more than five per cent.

most vital not only to living organisms, but to the entire economy of Nature.

Density.—As regards the density or specific gravity of water (which is by common consent assumed as the unit of comparison), it will be seen from the " Density " table that whereas all other bodies contract and become more dense as they grow colder, water has its point of (fluid) " maximum density " at 4° C. (49°.2 Fahr), and *expands* as it grows colder, until at 0° C. (32° Fahr.) it solidifies into ice. In so doing it departs still farther from the rule obtaining with all other bodies (excepting certain mixtures, such as type metal) and again expands so as to decrease the density from .99988 to .92800; thus causing ice to float on water at the freezing point. Hence water, unlike all other fluids, solidifies first on the surface; and but for this, the thawing of the winter's ice, which would be formed at the bottom of rivers and lakes, would be deferred until late in summer. The expansion of water in freezing is forcibly illustrated in the bursting of water pipes and pitchers in winter; in the soil, the ice forming in the interstices serves to loosen the compacted land and give it better tilth for the ensuing season.

Specific Heat.—Considering next, the column showing the " specific heat " of water as compared with other substances, we see that it exceeds all other known bodies in the amount of heat required to change its temperature; hence again, *its* heat capacity is taken as the unit to which all others are compared. The figures given in the table show that even ice and steam require for equal weights only about half as much heat (or burning of fuel) to change their temperature (*e. g.*, 1 degree) as would liquid water. But earthy matters, such as clay or soil and glass, require only one-fifth as much heat for a similar change; charcoal only about one-fourth as much. But vegetable matter as represented by wood on the one hand, and gold and lead on the other, require only about one-thirtieth as much heat as an equal weight of water; zinc about one-tenth as much, steel somewhat more.

It is thus plain that masses of water act powerfully, more than any other substance, as moderators of changes of temperature by their mere presence. The body of an animal or plant is protected against violent changes by the presence of from 60% to 90% of liquid water, the temperature of which can only be raised or lowered slowly; and the presence of the sea tempers the climates of coasts and islands as compared with the heat or cold occurring in the interior of the continents.

Ice.—Again, it is shown in the table that the heat required to *melt ice* is greater than in the case of any other substance, especially the metals; which when once heated to the fusing point, require only a very little more heat to become liquid. The fusion of salts (including silicate rocks) requires more heat than does that of the pure metals.

Vaporization.—In the amount of heat required for its *vaporization* water is also especially pre-eminent, and potent in its influence upon organic life. The table shows that the evaporation of water requires six hundred heat units [1] as compared with alcohol, requiring only two hundred; while spirits of turpentine, the representative of a large proportion of vegetable fluids, needs but sixty-seven.

The practical result is that evaporation of water from the surface of animals and the leaves of plants, is exceedingly effective in preventing excessive rise of temperature, the heat of the sun and air being spent in evaporating the perspiration of animals and plants before an injurious rise of temperature, such as would cause sunstroke in animals, and wilting or withering in plants, can occur. But since evaporation is most rapid in dry air, it follows that the cooling effect will be the greater in the arid regions than in the humid. In the latter, therefore, sunstroke is much more frequent than in the fervid regions of the arid west, even though the temperature in the latter may be higher by twenty or twenty-five degrees Fahrenheit. White men who would soon succumb if they attempted to work in the sun in Mississippi or Louisiana when the thermometer stands at 95°F. will experience no inconvenience under the same conditions in the dry atmosphere of the Great Valley of California.

Solvent Power.—To the exceptional properties of water discussed above, should be added another hardly less important one, viz., that of being an almost universal solvent especially of

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[1] A heat unit, or "calorie," is the amount of heat required to raise the temperature of a unit-weight (pound, kilogram, or gram) of water one thermometric degree. According to the unit-weight and thermometric scale used, the figures will vary, but in this text the basis is understood to be kilograms and the centigrade scale.

mineral matters, including even those which, like quartz, appear to be most insoluble and refractory (see chapt. 3). The water of the soil is thus enabled to convey to the roots of plants, in solution, all kinds of plant food contained in the soil. It should be noted that distilled (hence also rain-) water is a more powerful solvent, *e. g.*, of glass, than ordinary waters containing mineral matter, and even free acids.

Practically, plants take up *all* their water supply from the soil in the liquid form; and hence the soil-conditions with respect to this supply are of the most vital importance to plant growth. The most abundant supply of mineral plant food may be wholly useless, unless the physical conditions of adequate soil-moisture, access of air, and warmth, are fulfilled at the same time. On the other hand, comparatively few plants are adapted to healthy growth in soils saturated with water, or in water itself; and but few among these are of special interest from the agricultural standpoint.

Water-requirements of Growing Plants.—The amount of water contained in any plant at one time, however large, is but a small proportion of what is necessary to carry it through its full development. When we measure the amount of water actually evaporated through the plant in the course of its normal growth, we find it to be several hundred times the quantity of dry vegetable substance produced; varying according to the extent and structure of the leaf-surface, the number and size of the breathing pores (stomata) of the leaves, and the climatic conditions (including specially the duration of active vegetation, and temperature during the same), from 225 to as much as 912 times the weight of the mature, dry plant.

The following are extreme figures for water consumption of different plants as reported by different observers, viz., Lawes and Gilbert in England, Hellriegel in northern Germany, Wollny in Southern Germany (Munich), and King in Wisconsin: Wheat, 225 to 359; barley, 262 to 774; oats, 402 to 665; red clover, 249 to 453; peas, 235 to 447; mustard and rape, 845 to 912 respectively; the latter figure being the maximum thus far reported. The highest figures given are throughout very nearly those of Wollny, working in the very rainy climate of Munich.

Evaporation from Plants in Different Climates.—It might be expected that in countries where the air is usually moist, the evaporation will, other things being equal, be less than where it is commonly far below the point of saturation. But the "guardian cells" (stomata) of the leaf pores possess the power of regulating, to a certain extent, the evaporation from the leaf-surface in accordance with temporarily prevailing conditions, so as to allow free evaporation in moist air, but to prevent the wilting and drying-up of the leaf in hot and dry air, save in extreme cases. Moreover, plants adapted to arid conditions are usually provided with additional safeguards in the form of thick, non-conducting layers of surface cells, or long channels connecting the interior tissue with the breathing-pores on the surface. Often hairy, scaly or viscous coverings serve the same end. On the other hand, when the air is very moist, so as to check evaporation, water is sometimes found secreted in minute droplets around the breathing-pores of the leaves, since its ascent is a necessary condition of nutrition and development.

Relation between Evaporation and Plant-growth.—There is not in all cases any direct relation between the amount of evaporation and plant growth; but experience, as well as numerous rigorous experiments have shown that *under ordinary conditions of culture, and within limits varying for different soils and crops, production is almost directly proportional to the water supply during the period of active vegetation.*

On the basis of Hellriegel's results, showing that wheat uses (in Germany) about 435 tons, or nearly four acre-inches of water in the production of one ton of dry matter, and assuming the ratio of grain to straw to be 1:1.5, King calculates the following table of probable production under different moisture conditions (Physics of Agriculture, page 140):

YIELD PER ACRE.

Number of Bushels.	Weight of Grain. Tons.	Weight of Straw. Tons.	Total Weight. Tons.	Water used. Acre-inches.
15	.45	.675	1.125	4.498
20	.60	.90	1.500	5.998
25	.75	1.125	1.875	7.497
30	.90	1.350	2.250	8.997
35	1.05	1.575	2.625	10.495
40	1.20	1.800	3.000	12.000

S. Fortier has made several series of tests to determine the actual yield of grain crops under field conditions when supplied with different amounts of water. Two of these were made at the Montana experiment station in 1902 and 1903, (see reports of these years), in large tanks placed in a field, level with the ground. The results of the last year's experiments are shown graphically in the figure below, from which it will be seen that the yield increased quite regularly with the amount of water supplied, up to the depth of 36 inches of water.

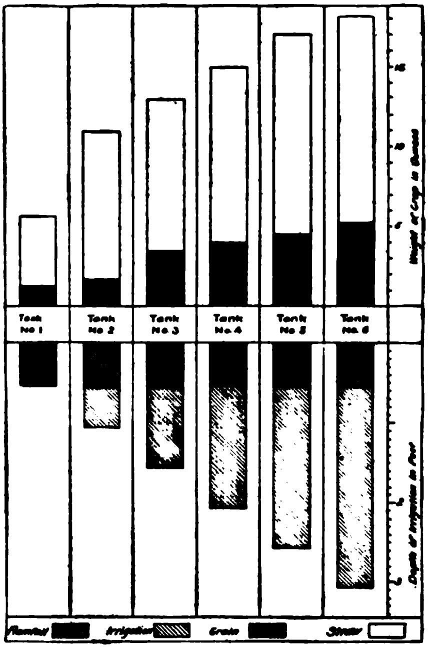

FIG. 1.

FIG. 37.—Experiments on Cereal production with various amounts of water (Fortier, Report Mont. Expt. Sta., 1903).

It should be noted that in this case (and as usual) not only the quantity but the quality of the grain was greatly improved as the water-supply increased, it becoming larger and more uniform in size.

Of similar experiments made in the San Joaquin Valley, California, in 1904, Fortier says:[1]

"In experimenting with barley last winter the natural rainfall, which amounted to 4½ inches during the period of growth, produced at the rate of nine bushels per acre, while the application of sixteen inches of water increased the yield to twenty-two bushels per acre. In the same case; of wheat, the rainfall, alone, produced straw, but no grain; four inches of additional irrigation water produced a yield at the rate of ten bushels, and sixteen inches of water increased the yield to thirty-eight bushels per acre."

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[1] "Water and Forest," January, 1905. "The Use of Water," by S. Fortier.

It is thus obvious that, other things being equal and with conditions sufficiently favorable for the growth of crops, the rule as formulated above is verified in practice.

Whitney (Bulletin 22, Bureau of Soils, U.S. Dept. Agr.), has carried this rule so far as to claim that in all soils, the moisture supply is the *only* important factor, and that so long as this is provided for, soil fertility continues indefinitely without replacement of ingredients withdrawn. The latter conclusion is so thoroughly disproved by experience as well as experiment that it hardly requires discussion here.

Whether plants, especially cultivated ones, are capable of adapting themselves to arid conditions so as to be capable of producing satisfactory crops with less water than is actually consumed in the humid region, has not been directly determined. Such is, however, the impression produced by farming experience; and the fact that among the common weeds of arid California are mustard and rape, cited by Wollny as requiring over three times as much water as does maize for the production of one part of dry matter, lends color to the supposition that in some manner these, and probably other plants, use more water in humid than in dry climates (see this chapt. p. 212).

It is therefore impossible to assign a definite figure for the amount of water required by vegetation *at large;* and even for one and the same plant, only approximations conditioned upon climatic factors can be given. We can in many cases, however, assign for one plant, or for certain groups of plants, the amounts of water producing the best results (" optimum ") and the least amount (" minimum ") compatible with a paying crop, that must be furnished during the growing season, to produce certain results. For when instead of fruiting, it is desired that the crop should produce the largest possible amount of vegetable substance, as in the case of forage crops, a larger amount of water will usually be serviceable.

Different conditions of Soil-Water.—Water may be contained in the soil in three different conditions, viz.:

1. From absorption of water vapor; Hygroscopic water.

2. Liquid water held suspended between the soil particles so as to exert no hydrostatic pressure; capillary water, or water of imbibition.

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[1] See Wollny's experiments, Forsch. Agr. Phys. Vol. 20, p. 58.

3. Liquid water seeking its level; bottom, ground or hydrostatic water.

HYGROSCOPIC WATER.

Soils artificially dried so as to deprive them of all their moisture, when exposed to moist air absorb water vapor with great energy at first; both the rapidity of absorption and the amounts absorbed, when full time is given, varying greatly with their nature. Sandy soils, broadly speaking, absorb the smallest amounts; while clayey soils, and those containing much humus, or finely divided ferric hydrate, take up the largest proportion.

The figure expressing the amount of aqueous vapor absorbed at the standard temperature of 15° Cent., is called the *coefficient of moisture absorption.* For one and the same substance, this coefficient rises as the grain becomes finer, the surface being correspondingly increased (see chapt. 6).

The table below indicates the effect of the three substances mentioned in increasing moisture absorption as compared with a very sandy soil from the pine woods of Mississippi, and a gray silt or "dust" soil from Washington, very fine-grained but poor both in humus and ferric hydrate. (For details of the physical composition of the Mississippi soils see table in chapt. 6, p. 93). A highly ferruginous soil from Oahu shows plainly the effect of that substance.

TABLE SHOWING INFLUENCE OF SILT, SAND, CLAY, FERRIC HYDRATE, AND HUMUS ON MOISTURE ABSORPTION.

	248 Miss. Pine Hills Sandy Loam. %	79 Wash'n Dust Soil. %	238 Miss. White Pipe Clay. %	230 Miss. Flatwoods Clay Soil. %	246 Miss. Ferruginous Clay Soil. %	Oahu. Ferruginous Laterite. %	220 Miss. Marsh Muck. %	215 Miss. Marsh Soil. %
Hygr. Moisture..............	2.48	4.92	9.09	9.33	18.60	19.66	21.00	15.40
Clay.................. ...	2.94	1.27	74.65	25.48	28.15	?	Tr.	Tr.
Ferric Hydrate.............	1.64	.....	.15	.....	12.10	41.00	.....	.....
Humus.....................	.55	.44	0.00	.50	little	3.33	66.10	19.83
Finest Silts (01–.0250 mm.)...	60.10	45.04	23.15	68.60	40.33	45.66	33.94	8.70
Sands, f. and c. (.0250–.50 mm.)	31.20	42.40	.20	4 70	15.61		.....	70.18

It will be noted that the greater fineness of grain in the Washington dust soil induces a higher absorption of moisture than occurs in the sandy soil from Mississippi, although the latter contains more clay. Comparison of the figure for the Mississippi pipeclay and clay soil with the ferruginous soils, from the same state and from Oahu, indicate plainly the influence of the ferric hydrate in increasing absorption; although in the latter case the clay determination was not made, because of the excess of ferric hydrate. The influence of humus is plainly shown in the case of the marsh muck and soil, neither of which contain any appreciable amount of either clay, or ferric hydrate in the finely diffused condition. The relatively slight difference in the absorptions of muck and soil is due to the only partial humification of the organic matter in the former, while in the soil the humification is sensibly complete, and the sand forming the body of the material serves to render it more loose.

These data, referring to natural materials, while not as complete as could be desired, are sufficient to prove the facts, and seem preferable to any artificially devised imitation of their kind.

Influence of Temperature, and Degree of Air-Saturation.— The amount of moisture absorbed varies materially both with the temperature, and with the degree of saturation of the air to which the soil is exposed. Schübler, Knop and other earlier observers, operating with earth exposed to air only partly saturated, and with soil layers of considerable thickness (in watch glasses), found that the absorption decreased as the temperature increased, according to a law formulated by Knop. The writer found that under the conditions established in the experiments of Knop and others, the air was not nearly saturated,[1] so that these determinations are marred by ineliminable

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[1] It should be understood that it is by no means easy to insure full saturation in any considerable volume of air.

It has generally been considered sufficient to cover with water the bottom of the space in which absorption was to occur. The writer found that in order to insure uniform results, it was necessary to cover the entire inner surface of the vessel with wet blotting paper, and even then to exclude carefully all circulation of air by padding the joints with such paper. When only the bottom of the box was covered, samples placed at different levels above the water surface gave discordant results. It was also observed that whenever the thickness of the soil faults, the more as the soils used are only designated in general terms, as "garden soil," "loam," "peaty land," etc., without any definite indication of their actual physical or chemical constitution. The writer therefore undertook to correlate these coefficients, determined with respect to completely saturated air, with the physical composition of certain soils, as determined by means of the methods heretofore described.

Some of the data so obtained are given in the table of physical soil composition on page 93, chapt. 6. They have since been extensively supplemented by additional determinations, but without materially changing the coefficients approximately corresponding to the several designations accepted in farm practice. Experiments conducted by the writer have conclusively shown that Knop's law of decrease of absorption with rise of temperature not only is not true for *fully* saturated air, but must be reversed; the fact being that the amount of water absorbed by the soil *increases in a fully saturated atmosphere* (i.e., in presence of excess of water) *as the temperature rises*, at least between 15 and 35 degrees Cent. Thus, fine sandy soil which at 15° absorbed 2% of moisture, took up 4% at 34°; while loam soil absorbing 7% at 15°, showed nearly 9% at 35°; an increase of 2% in each case. But in partially saturated air[2] it was found that, as stated by Knop, the amounts absorbed steadily decrease, though not according to the law announced by him. Taking as a unit the moisture absorbed at 15°, it was found that in air three-fourths saturated, ¾ of the unit was taken up by the soil; at half saturation, nearly the proportional amount; but at one-fourth saturation the earths absorb materially more than a similar proportion, being then capable of withdrawing moisture from greatly

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layer exceeded about one millimeter, a long time was required for full saturation; during which inevitable changes of temperature would bring about a deposition of dew on the soil, greatly exaggerating the absorptive coefficient.

In the chamber used at the California station for soil saturation, dimensions 12 × 18 × 19 inches high, the same soil was exposed on a shelf close to the surface of the water, another midway up, a third near the lower surface of the cover; liquid water being in the bottom of the chamber, and the rest covered with wet blotters. It was found that despite these precautions, the lowest soil layer absorbed in the same time as much as ¾ $^{\circ}/_{0}$ more than the uppermost one.

[2] The partial saturation to a definite extent was effected by means of solutions of calcium chlorid of different degrees of concentration, according to the determinations of Wüllner (Pogg. Ann.). These solutions were placed in a wide, flat dish, over which a layer of soil 1 mm. in thickness was exposed, all being covered with a bell glass lined inside with the same solution, so as to insure equal saturation.

undersaturated air. Since air thus undersaturated occurs not uncommonly in the arid regions of the world, the fact that the soil cannot be farther dried by such air of the same temperature, is of some practical significance.

In view of the highly variable composition of soils and of the doubtless varying hygroscopic properties of their several physical constituents, it is not to be expected that any one numerical law will hold good exactly for all kinds of lands. Mineral powders, colloidal clay, ferric hydrate, aluminic hydrate, the zeolites, humus, and other hydrates known to occur, doubtless each follow a different law in the absorption of moisture and gases; so as to modify the hygroscopic properties of the soil in accordance with their relative predominance in each case. (See table of absorption of gases, chapter 14).

Utility of Hygroscopic Moisture to Plant-growth.—The early experimenters considered the hygroscopic moisture of the soil to be of very great importance to the welfare of crops. Within the last twenty-five years much doubt has been cast upon this claim, even to the extent of stating that "the hygroscopic efficacy of soils must be definitely eliminated from among the useful properties" (Mayer's Agriculturchemie, vol. 2, p. 131). Yet Mayer himself concedes the cogency of the experiments made by Sachs, which proved that dry soil im-

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[1] E. A. Mitscherlich (Bodenkunde für Land-und Forstwirthe, p. 156 et al.) claims that all determinations of soil hygroscopicity thus far made are grossly incorrect on account of the dew liable to be condensed on the soil layer from fully saturated air, as the result of slight changes of temperature. He therefore would have all such determination made either in an air-vacuum, or over a 10% solution of sulfuric acid.

Such dew-formation, however, cannot happen to any appreciable extent under the conditions maintained in the writer's work, viz, absorption within a thick-walled (two-inch) wooden box of the dimensions given above, and sunk in the ground in a cellar in which the temperature varies only a few tenths of a degree during 24 hours. The soil layer of one millimeter thickness being put down in the morning, the 7 hour absorption period falls at the time of slightly rising temperature, as an additional precaution against dew-deposition. Mitscherlich fails, moreover, to show that this source of error produces any wide or serious discrepancies except under such long absorption periods as he finds it necessary to use because of the great thickness of his soil layers. It is doubtful whether the limits of errors in soil sampliug do not greatly exceed any of those involved in the writer's method, and whether such accuracy as is attempted by Mitscherlich is of any practical significance.

mersed in a (probably not even fully) saturated atmosphere is capable of supplying the requirements of normal vegetation; thus explaining the obvious beneficial effects on vegetation of the summer fogs prevailing in portions of the arid region, *e. g.*, on the coasts of California and Chile.

Mayer's experiments relied upon to prove the uselessness of hygroscopic moisture to plant growth, were carried out in flower-pots, in which it was plainly shown that the plants wilted before even the visible liquid (capillary) moisture of the earth was entirely exhausted. But this simply proves that under such artificial conditions, plants cannot withdraw moisture from the soil *rapidly* enough for their needs. In *nature*, and notably in the arid regions, the chief supply of water is received through the deep-going main roots, while the bulk of the active feeding roots of the plant may be surrounded by almost air-dry soil; under which conditions, as Henrici (Henneberg's Journ., 1863, p. 280) has shown, slow growth and nutrition occurs even in such plants as the raspberry, a native of humid climates. But in the arid region this is the normal condition of the native vegetation through most of the rainless summer. That a higher moisture-coefficient does not necessarily imply that a larger amount of moisture can be withdrawn from the soil by the plants, is undoubtedly true in some, but not in all cases; for in soils rich in humus, the moisture is more freely shared with the roots than in non-humous, clay lands.

The higher moisture-absorption is however of the most unquestionable service in the case of the occurrence of the hot, dry winds that so frequently threaten the entire crops of some regions. In this case the soil containing the greater amount of moisture requires a much longer time to be dried, and heated up to the point of injury to the roots, than in the case of sandy soils of low absorptive power, whose store is exhausted in a few hours and then permits the surface to be heated up to the scalding point, searing the stems and root crowns. That such injury occurs much sooner in sandy lands than in well-cultivated clay soils, is a matter of common note in the arid region.

Summary.—The significance of hygroscopic moisture in connection with plant growth may then be thus summarized:

1. Soils of high hygroscopic power can withdraw from moist air enough moisture to be of material help in *sustaining*

the life of vegetation in rainless summers, or in time of drought. It cannot, however, maintain normal growth, save in the case of some desert plants.

2. High moisture-absorption prevents the rapid and undue heating of the surface soil to the danger point, and thus often saves crops that are lost in soils of low hygroscopic power.

CAPILLARY WATER.

The liquid water held in the pores of the soil, in the form of surface films representing the curved surface seen in capillary tubes, and therefore tending to cause the water to move upwards, as well as in all other directions, until uniformity of tension is established, is of vastly higher importance to plant growth than hygroscopic moisture. It not only serves normally as the vehicle of all plant food absorbed during the growth of the usual crops, but also, as a rule, to sustain the enormous evaporation by which the plant maintains during the heat of the day, a temperature sufficiently low to permit of the proper operation of the processes of assimilation and building of cell tissue.

Comparatively few plants have roots adapted to healthy action while submerged in water, excluding them from free access of the oxygen of the air; and when such roots are formed by plants not naturally growing in water or swampy ground, they differ so far from earth roots in their structure that when transferred to soil they usually die, normal earth-roots being gradually formed instead. Conversely, there is for all land plants a definite time-limit beyond which their roots cannot live, or at least remain healthy, in submersion. Thus grain fields will with difficulty recover from a week's total submersion; while young rice fields will resist considerably longer. When in the resting (winter) condition vineyards will bear submergence for thirty-five and even forty days, deciduous orchards about three weeks; but when in the growing condition, injury is suffered much more quickly.

It follows that whenever the soil-pores remain completely filled with water for a length of time, there is danger to the welfare of nearly all plants commonly cultivated in the temperate zones. It is therefore important to know how much water will bring about this undesirable condition in the different kinds of soil.

To determine this point we may either employ the determination of pore space by a comparison of the density of the soil constituents (see chap. 7, p. 107) with the volume weight of the soil; or we may measure directly the amount of water required to fill the pore-space. For the latter purpose it is only necessary to measure the amount of water (conveniently flowing from a graduated pipette) which, rising slowly from below in a U-shaped tube so as to expel all the air before it, is required to fill a definite weight or volume of the soil entirely full, so as to rise to its surface. We thus ascertain the amount of empty space existing within the soil,[1] which in the absence of water will ordinarily be filled by air.

In most cultivated soils, as already stated, the air-space constitutes about 25% to 50% of their volume; and this space when filled with water represents what is commonly termed their *maximum water capacity* or saturation point. It is of interest to know this, because it has been ascertained from experience that in order that plants may reach their best development, the capillary water present should not amount to more than 60%, or less than 40% of its maximum water-holding capacity; thus leaving about half the pore-space filled with air. This optimum, however, varies somewhat for different plants, some, like celery, being more tolerant of excess, and others being more tolerant of a deficiency of moisture, as is the, *e. g.*, egg-plant, originally a desert growth.

Capillary Ascent of Water in Soil Columns.—When a column of dry soil (e. g., contained in a glass tube closed with muslin at the lower end) is brought in contact with water, the latter is soon seen to ascend in the soil, wetting it and thus changing its color so as to permit of ready observation of its progress. At first the rise is comparatively rapid, in some cases as much as an inch in one minute; but it soon slows down and after a time ranging from a few days to many

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[1] Simple as this operation appears to be, it is found to be by no means easy to expel with certainty every small air bubble without resorting to means which would destroy the natural condition of the soil; such as boiling, or the use of the air-pump. These determinations cannot therefore lay claim to great accuracy.

months, reaches a maximum height beyond which the liquid water will not rise. The ascent is most rapid, and stops soonest, in coarse sandy soils; it rises most slowly, but in the end considerably higher, in heavy clay soils. The most rapid continuous rise, and ultimately the highest, occurs in salty soils containing but a small proportion of clay. The maximum height of capillary rise thus far observed, viz. 10.17 feet, was noted in the case of quartz tailings from a stamp mill, ranging from .005 mm. to .016 mm. in diameter; but it took about 18 months' time to reach this maximum. The excessively fine texture of clay opposes great frictional resistance to the movement of the water, and the same is true of the finest silts, which, like clay, remain almost indefinitely suspended in water. But it must be remembered that while pure grains of silt will in wetting remain unchanged in size, clay particles, and the clay incrusting silt grains, will on wetting swell greatly, and thus fill up the interstices, largely closing them up against the passage of water.

These facts are exemplified and graphically illustrated below.

The soils selected for this illustration, from California localities, are the following:

No. 233. Very sandy soil from near Morano, Stanislaus County. Typical of the noted wheat-growing region of the lower San Joaquin Valley, from northern Merced to Southern San Joaquin Counties; bench or plains lands. First foot.

No. 1197. Sandy alluvial soil from near the confluence of the Gila and Colorado rivers, near Yuma. Very deep, light and easily cultivated. First foot, but almost identical to 15 feet.

No. 168. Silty alluvial soil from the old alluvium of the Santa Clara River, near Santa Paula, Ventura County. Very deep, very easily tilled; a typical alluvial loam of the arid region.

No. 1697. Black adobe or clay soil, from the experiment station grounds, Berkeley. A heavy clay soil, originally a swamp deposit, becoming very tenacious when wet. An excellent wheat soil.

The physical analyses of these soils are given below.

PHYSICAL ANALYSES OF TYPICAL SOILS.

	Clay.	Silt.		Sand, 2.0 to 64 mm. h. v.
		Fine, <.25 to .5 mm. h. v.	Coarse, .5 to 2. mm. h. v.	
No. 233. Morano sandy soil.....	2.82	3.03	3.49	89.25
No. 1197. Gila bottom soil.......	3.21	5.53	15.42	72.05
No. 198. Ventura silty soil......	15.02	15.24	25.84	45.41
No. 1697. Berkeley adobe soil....	44.27	25.35	13.47	13.37

The most striking feature in this diagram is the very rapid[1] and high ascent in the combination of sediments represented by the Gila bottom soil. It outstrips at once both the sandy soil from Stanislaus, which contains a trifle less of clay, and the silt soil from Ventura, from which at first sight it does not seem to differ widely, but which contains considerably more clay. It is doubtless the latter which so greatly retards the motion of the water, as is still farther seen in the case of the clay or adobe soil. It will be noted that on the second and third days, the Gila soil had raised the water nearly twice as high as the adobe, and that it took only 18 hours to raise it nearly the same height as that attained by the Ventura silt in so many days. But it ceased to rise after the 125th day, while the Ventura soil, continuing for 195 days, finally rose 3 inches higher. The adobe also continued its rise, but did not reach the same height as the Gila soil by nearly two inches. There can be no doubt that the energetic and high rise of the latter proves an important factor in the culture of these lands.

The coarse sandy soil reached its highest limit, 16½ inches, within six days, when the silty Gila soil stood at about double that height.

Ascent of Water in uniform[2] *Sediments.*—Loughridge has ascertained the rate of ascent of uniform sediments of different grain-diameters, with the results shown in the diagram

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[1] The ascent is of course most rapid, in the large tubes almost instantaneous, when the capillary space is entirely clear; but in the complex system of connected air spaces in soils, the curved paths and the friction obstruct the movement.

[2] I. e., uniform between the narrow limits given.

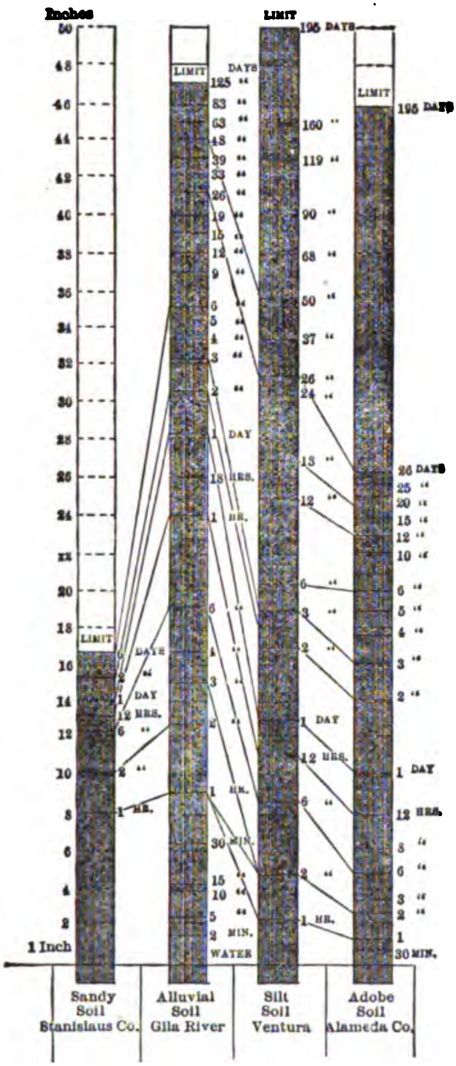

FIG. 38.—Columns showing heights to which water will rise by capillarity in soils of different physical composition, and rates of ascent.

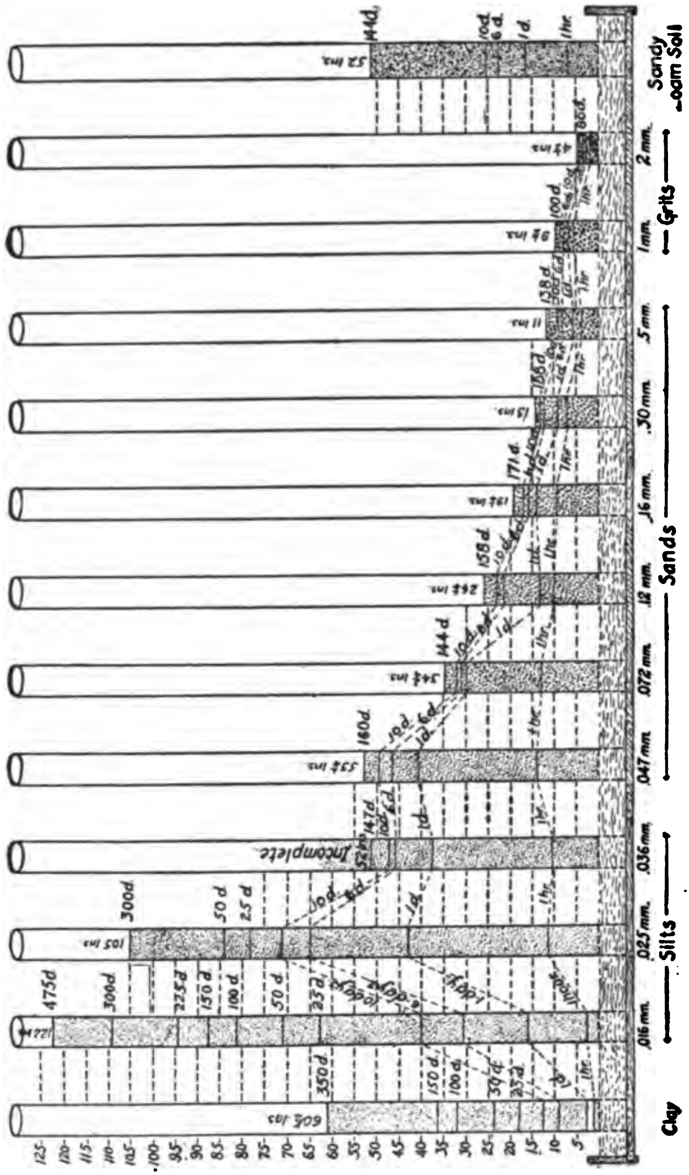

FIG. 39.—Capillary Rise of Water in Soil Sediments of different Diameters.

subjoined, together with the maximum height reached by each. The diagram is very eloquently illustrative of the great differences in the capillary properties of granular sediments of the various grades; and it would seem that it ought to be possible to deduce from it by a somewhat complex formula the rate and height of ascent of water in any soil of known physical composition. In nature, however, the presence of clay and the greater or less degree of flocculation of mixed sediments will always vitiate to a very great extent the results deducible from such calculations; hence the data conveyed by the observations of Loughridge must be considered applicable only to granular sediments free from clay and entirely deflocculated.

It is curious that in this case the "clay" showed a rise markedly below that of the finest granular sediment, despite the extreme fineness of its particles. This proves plainly that the physical nature of colloid clay is unlike that of the granular sediments; as has been repeatedly mentioned above.

Maximum and Minimum of Water-holding Power.—It is clear that at the base of the columns of soils just considered, the maximum of water-absorption of which the soil is capable will have been brought about; while at the top of the same column, the minimum of possible liquid absorption (continuous films of water) will exist. The same minimum moisture-condition will be produced when a limited quantity of water is placed with a large mass of soil; the moisture will spread to certain limits, until the surface films of water have all acquired uniform tension; and will then cease to extend, except by evaporation and hygroscopic absorption.[1] It is clear that the same condition will be brought about in the course of time at the top of a soil column in which water has percolated from above; and hence the minimum mentioned, aside from evaporation, represents approximately the usual condition of the soil

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[1] Ad. Mayer (Agriculturchemie 2, p. 141) designates this minimum content of liquid water as the "absolute" water capacity of the same; but it is not obvious wherein this factor is better entitled to this name than would be the maximum (see Wollny's Forsch., 1892, p. 1.). M. Whitney (Rep. Proceedings Ass'n Agr. Coll. & Exp't St'ns, Nov. 1904) gives as a new observation the fact that in soils approaching the drought condition water "does not obey the ordinary physical laws as we recognize them in capillarity." This evidently refers simply to the well-known phenomenon mentioned above.

near the surface within a variable time after a rain, or irrigation, when the descending water column has attained a length corresponding to the height to which the water would have risen from below in a tube arranged as shown on p. 205. It is therefore a condition of very frequent occurrence in the arid region.

Capillary Water held at Different Heights in a Soil Column.—To determine the amounts of water held in the different portions in columns of soils in which water ascends by capillary rise, the following plan was adopted by the writer in collaboration with Loughridge (Rep. Calif. Sta. 1892–4, p. 99).

Instead of glass tubes the soils to be tested were placed in copper tubes one inch in diameter, divided into segments six inches long, and flattened on one side. In the flattened side a slot half an inch wide was left, and glass plates, held in position by rubber elastics, were cemented on the slotted side by means of paraffin, to prevent a sifting-out of the soil. The short sections can be connected at the ends like joints of stovepipe, and the earths can be easily introduced in proper, even condition. It was thus possible to gain access to any portion of the column at any time, for the taking of samples.

WATER CONTENTS OF SOIL COLUMNS AT VARIOUS HEIGHTS ABOVE WATER LEVEL.

No.	233	1197	1679
Height above Water Level.	Sandy Soil, Morano.	Sandy Alluvium, Gila.	Adobe, Berkeley.
47 inches		4.33	
42 inches		10.26	
36 inches		11.99	
30 inches		15.26	
24 inches		21.39	10.26[1]
18 inches		27.63	29.48
12 inches	3.93	32.48	33.04
6 inches	14.15	35.04	38.47
3 inches			38.49
1 inch	24.34	36.64	44.41

Since gravity limits the capillary ascent in a progressive ratio, as shown in diagram 39, it is obvious that the true *maximum* saturation

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[1] This figure represents only a temporary condition; the full height of 46 inches was not reached until the 195th day.

can exist only in a very short (strictly speaking, an infinitesimally short) vertical column. The least practicable height for experimental work being about 1 cm. (⅜ in.), the writer has adopted for the purpose of rapid determination of this factor, the use of a brass cylinder 1 cm. high and of such width as to contain, for the sake of convenience, 25 or 50 cm. of soil. This cylinder has a finely perforated bottom, which may be covered with filter paper; after being filled with soil which has been struck level, and weighing, it is immersed to 1 mm. depth in distilled water and allowed to rest for an hour; then quickly dried outside and beneath with filter paper, and again weighed. The amount of water found by difference should for all practical purposes be referred to the volume, not to the weight, of the soil, so as to eliminate the error arising from the varying specific gravity of the latter.

In most cases the surface of the soil in the sieve cylinder remains level after wetting; but sometimes it swells so as to rise above its dry level, even to the extent of nearly 30% (see chapter 7, p. 114). This happens especially in strongly ferruginous soils. In the case of "black alkali" soils, in wetting an enormous *collapse* sometimes takes place (see chapter 22).

If it be desired to determine also the *minimum* liquid absorption (see below), the surface of the wet soil is first covered with air-dry soil, to absorb the surplus moisture, and finally with soil previously saturated with hygroscopic moisture; the added soil being each time thrown off and finally the surface "struck" level with a tense silk thread before weighing. Corrections must be applied for the usual increase in weight, from the addition of soil, and for the hygroscopic moisture.

While the *minimum* of liquid absorption can thus be determined quickly, without awaiting the capillary ascent of a water column, and if sufficient time is given can also be determined in higher columns, as proposed by Mayer (Wollny's Forsch. Vol. 3), the *maximum* cannot thus be determined without gross inaccuracy. In determinations made by the writer it was found that the figures for the minima of very different soils (clayey and sandy) of the arid region, differ proportionally much less than do the respective maxima. In few of these soils it was found to exceed about 10 per cent, and it scarcely fell below 4 per cent even in very sandy soils. A very deep, sandy soil, which had been irrigated in May, and upon which no rain had since fallen, showed in July in the second foot, upon which rested ten inches of fully air-dried soil free from vegetation, a water-percentage of eight per cent.[1]

Capillary Action in Moist Soils.—In the preceding discussion the case of columns of air-dry soils, so common in the arid regions, has been considered. It is obvious that a soil column holding the *minimum* of capillary water may be of any height; so that when, as happens in the open field, the rain water soaks down beyond the range of capillary rise in a given soil, the upper portions of the latter, above that range, will remain at the minimum of moisture-content so long as it is not depleted by evaporation. King has made extended observations on soil columns ten feet high and moistened throughout the mass. Capillary movement takes place in moist soils much more rapidly than in dry ones, although when sufficient time is given the final adjustment will of course be the same. King's experiments showed that evaporation at the surface of the tenfoot columns caused a sensible depletion of the water content originally existing at the depth of ten feet, in the course of 314 days. While so slow a movement might not be of any benefit during the growth-period of shallow-rooted annual crops, the fact shown is of importance to permanent plantings, as of trees and vines.

Another and not so readily intelligible effect observed by King is that when the surface-soil is wetted, moisture may be withdrawn toward the surface from the lower layers. In one experiment he found that when water was applied on the surface so as to add two pounds of water to *each* surface foot in several soils, at the end of 26 hours there had been an increase of *three* pounds in the same, and a loss of one and three quarter pounds from the second and third feet. The cause of this translocation is probably a "distillation" of the subsoil moisture toward the cooled soil; the fact that it occurs is of practical interest, since it seems to show that wetting the upper

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[1] Hall (The Soil, p. 66) gives for the minima in the case of soils examined by him the following figures: coarse sandy soil, 22.2, light loam, 35.4, stiff clay, 45.6, sandy peat, 52.8. These figures are very much higher than for apparently similar materials used by the writer, and the differences exceed those between the maxima given for the same. This discrepancy I am unable to account for.

portion of the soil by cold rain or irrigation may tend to raise additional supplies from below. At the change of seasons we not uncommonly find, in digging tree holes or wells, a wet streak at from 9 to 18 inches below the surface, caused evidently by the condensation of subsoil moisture, at the limit of a cold zone resulting from the penetration of unseasonable temperature ("cold snap") from above. Such movements of soil-moisture by means of evaporation and recondensation within the soil can of course take place even when the minimum of liquid absorption has been reached and direct capillary movement has ceased. It is, as it were, dew within the soil.

Proportion of Moisture Available to Growing Plants.—Not all the capillary moisture contained in soils is available to plants, as can readily be seen from the fact that many plants, especially when growing in pots, begin to wilt while the soil still appears visibly moist. The limit of wilting differs greatly in different plants, and in the open ground it is difficult to ascertain that limit, because the deeper roots continue to supply moisture from moister substrata. Hence potted plants wilt while the soil appears much moister than when the same grow in the field. King[1] has determined the amounts of moisture down to 43 inches in a Wisconsin soil in which clover and corn were at the wilting point, as in the following condensed table:

	Clover.	Maize.	Fallow ground.
First 12 inches, clay loam	8.44	7.03	17.01
Second 12 inches, reddish clay	12.84	11.79	19.86
24 to 30 inches, sandy clay	13.52	10.84	18.56
40 to 43 inches, sand	9.53	4.17	15.90

It is plainly shown here that the roots of clover and corn were unable to utilize the higher moisture-content of the subsoil-clay to the same extent as the smaller amounts present in the surface foot, and in the sandy substrata. Evidently the moisture in the clay soil was more tenaciously retained.

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[1] Physics of Agriculture, p. 135.

This is doubtless due, as King shows, to the equal thinness of the moisture film remaining on the soil grains in either case; the number of grains, and therefore the aggregate surface holding these films, being much greater in the clay than in sands; hence the higher water content.

It is interesting to compare these figures given by King for clover and maize at the wilting-point, and fallow ground adjacent, with those given by Eckart (Rep. Expt. Sta. Haw. Sugar Planters' Ass'n., 1903) for those affording good growing conditions for sugar cane on the (highly ferruginous) soils of that station. The plots were irrigated at the rate of one, two and three inches of water per week, allowance being made for the rainfall. Two inches proved, on the whole, to give the best average results for production. The moisture determination of the soil under the two-inch regime gave an average moisture content of 29.13% in the first foot of soil. It is not stated what was the hygroscopic coefficient of that soil, but it was probably very high; in the neighborhood of 21.5%, judging by the determinations made with six Hawaiian soils at the California Station. This would indicate about 7.63% of free moisture as the optimum for sugar cane.

Moisture-requirements of Crops in the Arid Region.—Plants (particularly broad-leaved ones) which have made a brash growth during a period of abundant moisture, will wilt quickly when sunshine returns, and take some time to adapt themselves to the drier conditions. On the other hand, plants accustomed to dry air and scanty soil-moisture, will not wilt or suffer under what would elsewhere be considered very rigorous conditions. Loughridge[1] has made numerous determinations of moisture in soils in which crops were beginning to suffer, and others on similar soils that were growing normally, and found that in general, not only were the differences in moisture content considerably less than in the case above quoted from King's observations, but that the amounts of free moisture required by various crops in the arid climate of California were surprisingly small.

The tables below show the results of observations made by

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[1] Rept. Cal. Expt. Sta. 1897–08, pp. 65–96.

Loughridge during several drought years in California; so arranged as to show the differences of moisture content for the same crop in different soils. It will be observed that in all cases where a crop growing on a clay soil could be compared with the same on a lighter soil, the moisture required to keep the crop in good condition was very much greater in the clay than in the loam or sandy soils. In the case of apples, *e. g.*, 8.3% of water was abundant to keep the trees in excellent condition on a loam soil, while on a clay soil holding 12.3% the condition was very poor. That this difference is due in the main to the difference in the hygroscopic-moisture coefficient of the respective soils, is plainly apparent in several cases. It is therefore not the *total* moisture content, but the free moisture present in excess of what is held by hygroscopic absorption, that determines the welfare of the plant.

By determining, first, the total moisture in the soils, as taken in the field, then, after allowing them to become air-dry, determining the maximum of hygroscopic moisture they would absorb (see p. 198), Loughridge found by difference the amount of free moisture, or liquid water which must be present in the soil to prevent the crops from suffering. An exceptionally good opportunity for these observations was offered by the dry season of 1898, during which crops suffering and not suffering, on identical lands, could easily be found. The determinations were always made for each foot of the upper four feet of the land in the immediate neighborhood of the trees or among the field crops. The first table exemplifies the method of procedure; the second gives the summary of results for the several crops and trees, as calculated from observations made during the season.

TABLE SHOWING CONDITION OF CROPS ON VARIOUS SOILS UNDER DIFFERENT MOISTURE-CONDITIONS.

Kind of Crop.	Kind of Soil.	Condition of Crop.	Per cent Moisture in four feet.			
			Total.	Hygroscopic.	Free.	Tons per acre.
Wheat	Very sandy	Poor	2.6	1.9	.7	56
"	Sandy loam	Good	12.8	5.6	7.2	576
"	Clay	Dead	14.1	10.5	3.6	288
Maize	Clay adobe	Very good	12.9	8.8	4.1	328
"	Sandy loam	Fair	6.1	2.3	3.8	304
Barley	Black adobe	Wilting	10.7	8.8	1.9	152
Sugar Beets	Black loam	Good	12.4	5.6	6.8	544
Vines	Loam	Good	8.5	5.0	3.5	280
"	Sandy loam	Poor	1.9	1.5	.4	32
Almonds	Loam	Good	8.5	6.6	1.9	178
"	Same field	Suffering	7.9	6.9	1.0	80
Apples	Loam	Excellent	8.3	5.5	2.8	224
"	Clay	Poor	12.3	10.8	1.5	120
Apricots	Loam	Excellent	6.3	3.3	3.0	240
"	Gravelly loam	Poor	6.9	5.0	1.9	152
Figs	Red loam	Good	5.2	3.8	1.4	112
"	Heavy loam	Wilting	8.6	8.6	0	0
Olives	Red loam	Good	5.2	3.8	1.4	112
"	Sandy loam	Suffering	1.9	1.9	0	0
Peaches	Red loam	Good	8.2	5.0	3.2	256
"	"	Poor	6.8	5.0	1.8	144
Prunes	Gray loam	Excellent	11.2	9.0	2.2	176
"	"	Poor	6.4	5.4	1.0	80
Citrus fruits	Sandy loam	Good	6.3	3.1	3.2	256
" "	Sandy soil	Leafless	3.1	2.4	.7	56

TABLE SHOWING DROUGHT-ENDURANCE OF VARIOUS CROPS IN ARID REGION.

Free water in four feet of soil.		Crops that did well in lowest amount of moisture mentioned in first column.	Crops that suffered in highest amount of moisture mentioned in first column.
Per cent.	Tons per acre.		
0 to 1.0	80	Apricots, Olives, Grapes, Peaches, Soy-bean.	Citrus, Pears, Plums, Acacia.
1.0 to 1.5	120	Citrus, Figs.	Almonds, Apples.
1.5 to 2.	160	Almonds, Plums, Saltbush.	Barley.
2 to 2.5	176	Prunes.	
	200	Walnuts, Eucalyptus.	Prunes.
2.5 to 3	224	Apples.	
3 to 3.5	288	Pears.	
3 to 4	322	Hairy Vetch.	Wheat.
4 to 5	400	Wheat, Maize.	
5 to 6	480	Sugar beets, Sorghum.	Sugar beets.

CHAPTER XII.

THE WATER OF SOILS.—*Continued.*

SURFACE, HYDROSTATIC AND GROUND WATER; PERCOLATION.

SINCE all the water of soils and plants is directly or indirectly derived from the rainfall (including therein snow and hail), some general points regarding this factor require first consideration. While it is not the object of this work to discuss climatology in detail, yet the times of the year and the manner in which precipitation comes, acts upon and is disposed of in the soil under different climatic conditions, must of necessity form an essential part of its subject matter.

Amount of rainfall.—The rain falling in the course of a year is usually stated in the form of "inches" (or centimeters), implying the height of the water column that would be shown at the end of the year had it all been allowed to accumulate; or, the sum of all the successive rains (including snow) observed during the year. Since this amount ranges all the way from nothing, or a mere fraction of an inch (as in portions of the Andes, and of the great African and Asian deserts) to as much as 600 inches or fifty feet (Cherapundji in eastern India), the adaptation of agricultural practice to the maintenance of the proper moisture-supply to crops is largely a local question, oftentimes of not inconsiderable difficulty. This is especially the case where torrential rains, yielding several inches of rain in a few hours, alternate with light, soaking rainfall, as is very commonly the case in the interior of continents, and more especially in the United States east of the Rocky Mountains. Westward of the same the rainfall decreases so rapidly that at or about the one-hundredth meridian (the longitude of Bismark and Pierre, Dakota, and Dodge City, Kansas) we already reach the annual average of 20 inches, which is commonly assumed to be the limit below which crops cannot safely be grown without irrigation. The "cloudbursts" occasionally occurring within these limits are usually confined to mountainous regions, and the water they pour down on the dry soil is rarely of any direct benefit to agriculture; hence they cannot be properly counted in the general estimate of the effective rainfall. A region of high rainfall (up to 100 inches and over), however, extends along the Pacific coast from northern California through western Oregon and Washington across British Columbia to Alaska, to seaward of the Sierra Nevada, Cascade, and Alaskan coast ranges.

In the country east of the Mississippi river, the average annual rainfall ranges from 30 inches in the region of the Great Lakes, and 45 to 50 inches on the north Atlantic coast, to 60 inches in Louisiana and up to eighty in southern Florida. The average of the Mississippi Valley and Atlantic coast States is usually stated at about 45 inches, which is distributed more or less evenly throughout the year, excepting usually from six to eight weeks of more scanty precipitation in the latter part of August and in September—the "Indian summer" season; so that the winter is the season of greatest total rainfall.

Natural disposition of the Rain Water.—The rainfall is naturally first disposed of in two ways, viz., a portion which is absorbed by the soil, and another which is at once shed from the surface and constitutes the "surface runoff." The portion absorbed into the soil is subsequently disposed of either by soakage downward into the subdrainage and through springs and seepage[1] into the streams and rivers; or by evaporation. The latter again occurs in two different ways, viz., from the soil-surface itself, or through the roots and leaves of plants. The importance of each of these modes is sufficiently great to entitle each to detailed consideration.

The Surface Runoff.—This portion of the disposal of rain may range all the way from nothing to almost totality, according to the nature of the soil and the condition of its surface.[2]

[1] The quiet seepage from the banks and beds of streams plays a much more important part in the increase of volume of flow than is commonly supposed, because unperceived save by measurement of the tributaries and comparison with the main streams. This is especially true of the drainage in the arid region, where the deep and pervious soils favor diffuse seepage as against definite spring flow.

[2] Toumey (Yearbook U. S. Dep't Agr. 1903) states that in the San Bernardino mountains in southern California, the first rainfall (in December) was absorbed to the extent of 95% in forested areas, against only 60% in the non-forested; but

Sandy soils, especially when coarse, may absorb instantly even a very heavy rainfall. Heavy clay soils when dry will at first also absorb quickly quite a heavy precipitation; but as the beating of the raindrops compacts the surface, the absorption quickly slows down, so that heavy downpours of brief duration, while wetting thoroughly into a plastic mass the first two or three inches of a clay soil, may leave all beneath dry, to be very gradually moistened by the slow downward percolation against the resistance of the air in the soil; while the greater part of the later portion of the shower will drain off the surface in muddy runlets. Certain soils classed as loams, having the property of crusting readily by rain followed by sunshine (see chapter 7, p. 111), in heavy showers behave hardly better than strong clay soils; shedding the water until the soaked crust gives way, and is carried off in muddy streamlets. Then begins the cutting-away of the soil that, in portions of the Cotton States, as well as north of the Ohio river, has been the cause of extensive devastation of once fruitful culture lands, the site of which is now marked by " red washes " and gullies but too familiar to the eye in many regions, especially of the southern United States.

Washing-away and Gullying in the Cotton States.—Nowhere perhaps have these effects been so severely felt as in portions of northwestern and central Mississippi, and this case is so instructive as to deserve a more detailed description. In the regions in question the soil stratum consists of a yellow or brownish loam from three to seven feet in original thickness, constituting a very desirable class of gently rolling uplands, which at one time claimed to be the best cotton-growing portion of the State. It was originally covered with an open forest of oaks, with an abundant growth of grasses that afforded excellent pasture to deer and cattle; a natural park gay with flowers during most of the season.

When these lands were taken into cultivation little or no attention was paid to the direction of the furrows and rows of corn and cotton;

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that later, after the soil had been partially saturated, 60% only was absorbed in the forested land, against 5% in the non-forested. While it is generally admitted that forests diminish the runoff, Rafter (Relation of Rainfall to Runoff, U. S. Geol. Survey Paper, No. 80, p. 53) contends that in New York State the reverse is true.

most commonly the plowing was done "up-hill and down," so that the "dead-furrow" afforded a ready opportunity for the formation of washes cutting into the subsoil, during the torrential rains sometimes falling during the summers. Even when filled with soil by plowing, these washes would frequently re-open during rains, shedding the soil in a muddy flood upon the lower lands. The washing-away of the surface soil, thus brought about, of course diminished the production of the higher lands, which were then commonly "turned out" and left without cultivation or care of any kind. The crusted surface shed the rain water into the old furrows, and the latter were quickly deepened and widened into gullies—"red washes"—whose presence rendered any resumption of cultivation difficult. In the course of a few years the soil-stratum of brown loam was penetrated into the loose or loosely cemented sand which underlies it almost everywhere, and is very readily washed away. Soon the water, gaining yearly in volume, undercut the loam stratum so as to cause it to "cave" into gullies in huge masses,

FIG. 40.—Erosion in Mississippi Table Lands, causing destruction of agricultural value both of Uplands and Valleys. (McGee, 12th Ann. Rept. U. S., 1890-91.)

FIG. 40a.—Erosion in Mississippi Table Lands, causing destruction of agricultural value both of Uplands and Valleys. (McGee, 12th Ann. Rept. U. S. G. S., 1890-91.)

which with the sand were carried into the valleys adjacent, filling the beds of the streams so as to cause their flow to disappear under the flood of sand. As the evil progressed, large areas of uplands were denuded completely of their loam or culture stratum, leaving nothing but bare, arid sand, wholly useless for cultivation; while the valleys were little better, the native vegetation having been destroyed and only hardy weeds finding nourishment on the sandy surface.

In this manner whole sections, and in some portions of the State whole townships of the best class of uplands have been transformed into sandy wastes, hardly reclaimable by any ordinary means, and wholly changing the industrial conditions of entire counties; whose county seats even in some instances had to be changed, the old town and site having, by the same destructive agencies, literally "gone down hill." This destruction of lands was greatly aggravated by the civil war, during which, and for some time after, large areas of lands once under cultivation were left to the mercy of the elements.

Injury in the arid regions.—In the arid regions, where the rainfall frequently comes in heavy downpours or "cloudbursts," immense damage to pasture lands has been brought about by overstocking, in Arizona and New Mexico; involving the destruction of the natural cover of vegetation and the loosening of the surface especially by sheep; after which a heavy rainfall will carry off the surface soil, the muddy water being gathered largely in the trails made by cattle going to water. Thus gradually gullies are formed, which enlarging more and more become ravines and cut up the pasture slopes into "bad lands," useless equally for pasture and for agriculture.[1] California, eastern Oregon and Washington, and Montana, offer striking and lamentable examples of the same destructive agencies.

Deforestation.—The deforestation of hill and mountain lands has, the world over, led to similar results; causing not only the destruction of pasture and agricultural lands, but also the conversion of streams, flowing from springs and seepage all the year, into periodic torrents, flooding the lowlands during rains by the rapid running-off of the water from the bare and hard-baked mountain slopes, and then running dry

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[1] Open Range and Irrigation Farming. R. H Forbes, in Forester, Nos. 7, 9, 1902.

within a short time, so as not even to afford drinking water to pasturing cattle in summer. Thus for half a century the unsolved problem of the "correction of the waters of the Jura mountains" was before the Swiss and French governments; and the great and costly public work involving re-forestation, deflection of torrents and filling-in of deep ravines and gullies, is not even yet nearly completed. In Spain, which in the time of the Roman occupation was largely a forest country with abundant rainfall, the same results are seen, notably in the South, in the wide, and mostly dry, sandy beds of streams once running deep and clear; and in the scarred hill-and mountain-sides, and scant vegetation of low shrubs ("chaparral") that replaces the once abundant tree growth, *e. g.*, in Old and New Castile. Unfortunately the lessons taught by the bitter experience of the old world seem to require actual repetition in the new, before means of prevention are even thought of.

Prevention of Injury to Cultivated Lands from excessive Runoff.—The fundamental remedy for the injurious effects of excessive runoff from the land surface is, of course, to facilitate its absorption into the soil to the utmost extent possible, by deep tillage; or in cases where this is undesirable (as when in rainy climates excessive leaching of the land is feared), to so direct and control the surface drainage that its flow shall nowhere be so rapid as to carry with it any large amounts of earth, or to wash out the furrows. To this end its fall must be diminished by "circling," *i. e.*, plowing nearly at right angles to the slope instead of up-and-down, and on steep slopes especially also by maintaining open furrows or ditches having a gentle fall only, into which the water can shed and flow off quietly in case the furrows, left in plowing, prove insufficient to retain and shed gradually the water they cannot hold permanently. The early adoption of this simple expedient would have wholly prevented the enormous waste of fine agricultural lands referred to above.

The underdraining of lands liable to washing is a costly but highly effective means of preventing denudation; and the laying of underdrains in gullies already formed, to prevent farther deepening, is among the most obvious means of arresting farther damage. The beneficial effects of underdrainage in conserving moisture will be discussed farther on.

ABSORPTION AND MOVEMENTS OF WATER IN SOILS.

The phenomena and laws of capillary ascent of water in soils, as discussed in the preceding chapter, serve best to demonstrate the general behavior of liquid water within different soils and their several grain-sizes; because measurably independent of the physical changes that almost unavoidably accompany the percolation of water from above downward; whether such water comes in the form of rain, or irrigation, or even when applied with the utmost precautions in the laboratory. The "beating" of rains quickly compacts the surface to a certain extent, varying with the nature of the soil, its condition of more or less perfect tilth, and the degree of violence with which the rain strikes the surface. When the latter has been compacted by a previous rain and then dried, "baking" or incrusting the surface, the latter may almost wholly shed a rain of brief duration, which, had the surface been loose, would have been wholly absorbed, materially benefiting the crop. Such surface-crusting is, therefore, injurious in preventing the absorption of water from above; and in addition, it serves to waste, by evaporation, the moisture contained in the underlying soil and subsoil. For the crust being of a finer (single-grain) texture than the tilled portion beneath, it will forcibly abstract from the latter, by absorption, its capillary moisture, and evaporating it at the upper surface, continue to deplete the land, to the great injury of crop growth, until destroyed by cultivation.[1]

The flow of irrigation water produces the same compacting effect, but to a less extent; the more as, unlike rain water, irrigation water usually contains a certain amount of alkaline and earth salts, which tend to prevent the diffusion of clay and of fine sediments, and therefore the disintegration of the soil-floccules into single grains. Nevertheless, it is in some soils as necessary to cultivate after surface-irrigation as after rains, in order to prevent great waste of moisture by evaporation.

Determination of rate of percolation.—When water is al-

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[1] This effect is well illustrated by the behavior of a dry brick laid upon a wet sponge. It will quickly absorb all the liquid moisture contained in the latter, while the sponge will be wholly unable to take any moisture from a fully-soaked brick.

lowed to soak into an air-dry soil column without sensible shock or motion, from a constant level, we obtain the nearest approach to a definite determination of the relative permeability of soils to water under the conditions usual in the arid region. A number of determinations thus made is tabulated in the diagram given below, which embodies the observations made by Mr. A. V. Stubenrauch [1] in connection with a more extended investigation.

As these experiments were made with soils not in their field condition, but gently broken up with a rubber pestle, a standard of compactness was established by weighing the quantity which could conveniently be settled into a tube space of 100 centimeters capacity by tapping the sides and bottom of the tube, without touching the soil itself. In this way the following standards were established: For the University Adobe soil, 140 grams; for the Yuba loam soil, 110 grams; for the Stanislaus sandy soil, 170 grams. Tubes 1½ inches wide were used, and the soils were introduced in bulk, inside of a cylinder of stiff paper upon which previously to rolling it up the soils had been thoroughly mixed. After introducing the soil-filled paper roll it was gently withdrawn, leaving the soil column in the tube as uniform as before; a condition almost impossible of fulfilment when the soil is introduced piecemeal. The tubes were, of course, left open at the lower end, using a wire netting to keep the soil column in, so that the air could escape freely before the descending water column.

The results thus obtained do not, of course, apply directly to the same soils undisturbed in place in the field; where, moreover, the air is confined by the wetting of the surface and thus directly opposes penetration of the water. Still, they doubtless give a correct idea of their *relative* permeability for water when in the tilled condition. The water level was automatically maintained at the depth of half an inch above the surface of the soil columns. Pore-spaces given are calculated from volume-weight and specific gravity.

This diagram shows plainly that there is no direct relation between the total pore-space in a soil and the facility of water-penetration. The highest pore-space, in the fine-grained alluvial loam, allows more rapid percolation than the heavy clay or adobe soil, but is greatly exceeded by the coarser sandy soil. In all it is very apparent that the downward movement slows down as the water descends, doubtless because the great friction in a longer column gradually diminishes the effect of hy-

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[1] Rep't Calif. Exp't Station for 1898 to 1901, p. 165.

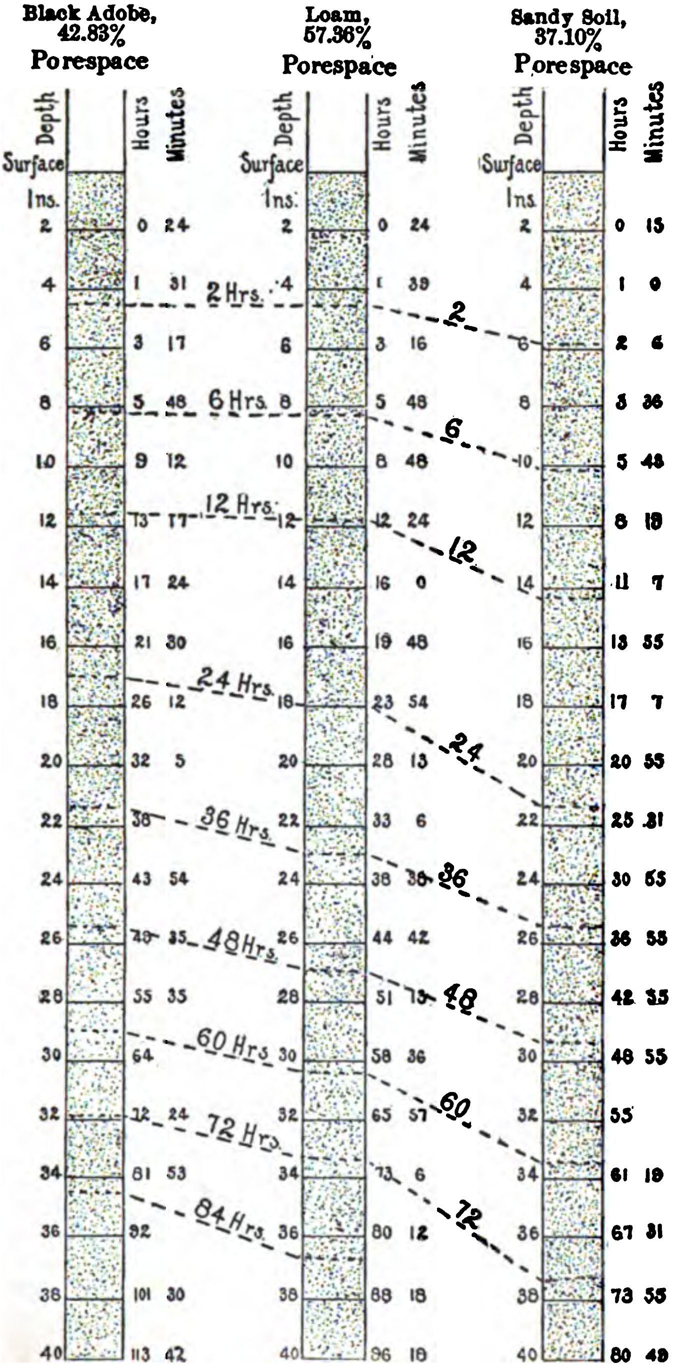

Diagram showing differences in rates of percolation through different soils drostatic pressure. It may be presumed that at a certain distance from the surface the downward movement becomes practically uniform, and independent of the pressure from above.

Summary.—Two salient points are revealed by even a cursory inspection of the preceding diagram, viz.:

1. The downward percolation is most rapid in the same soils in which the capillary ascent is quickest, that is, in the coarse, sandy soil.
2. The rapidity of percolation decreases materially as the wetted soil column increases in length.

The first point is readily foreseen and needs no comment. As regards the second, it results from the fact that as the wetted column lengthens the frictional resistance increasingly counteracts the effects of the hydrostatic pressure from above, until the water's descent becomes but little more rapid than would be its lateral diffusion, or its ascent at the end of a similar column supplied by capillary rise from below. In both cases the frictional resistance has so far counteracted the effect of gravity that the capillary coefficients of the soil-material become the controlling factors of the water movement.

Influence of Variety of Grain-sizes.—King (Physics of Agriculture, pp. 159 ,160), compared the rapidity of the percolation of water through definitely graded pure sands on the one hand, and a sandy loam and a clay soil on the other. The materials were arranged in 8-foot columns fully saturated with water at the outset, and then allowed to drain freely. The following abridged table shows the tenor of his results:

TABLE SHOWING RELATIVE RAPIDITY OF PERCOLATION IN PURE SANDS AND SOILS, IN INCHES OF WATER DRAINED OFF.

Diameter of Uniform Sand Grains.	First 30 minutes	Second 30 minutes.	Total in one hour.
.475 mm.	10.25	4.68	14.93
.155 "	5.67	4.52	10.19
.083 "	1.21	.85	2.06

Soils.	First 21-23 hours.	First 10 days following.	Second 10 days following.	Total in about 505 hours.
Sandy loam...............	2.64	5.07	.91	8.62
Clay loam................	1.96	2.11	.49	4.56

This table is very instructive in showing the great difference in the rapidity of percolation in materials of uniform, even-sized grains, as compared with such as contain particles of many different sizes, in which the interspaces of the larger ones are filled more or less closely by the smaller sizes of particles (see chapter 7, p. 109). While it is true that we have no definite physical analysis of the soils here used, the differences are so great as to be sufficiently striking. Compare the percolation through the sand of .155 mm. uniform grain-size (a fine sand), during the first half hour, with that through the sandy loam during the first 21 hours. Twice as much water has passed from the sand as from the soil in one forty-second part of the time. Comparing similarly the finest sand, .083 mm. in diameter, with the clay loam, we find the difference to be as one to seventy-three. It is thus evident that but for the variously assorted sizes of the soil-particles, water would not be held long enough to supply plant growth.

Percolation in Natural Soils.—In artificial percolation experiments, as well as during a fall of rain, the gradual settling of the fully wetted soil-column produces a compacting of that portion of the mass, that increasingly impedes the downward penetration. The effect of this under natural conditions is readily seen in the fact that after the first, rapid absorption of falling rain by the soil when in good tilth, there is a gradual slackening of the process even when the rain is fine and slow, causing a perceptible increase of the runoff until, should the rain continue for some time, the absorption becomes so slow as to cause all, or nearly all the water to drain off the surface. The soil is then called " saturated," having really arrived at that point right at the surface, and to a depth varying according to the duration and amount of rain, and the natural perviousness of the land.

When the rain ceases, the visible saturation of the surface usually soon disappears in cultivated soils, and the zone of saturation begins to descend. The progress of this descent may be very strikingly observed in a series of holes (post-holes) dug or bored across a ridge; as indicated in the subjoined schematic diagram, in which the successive dotted lines represent the levels of the descending " bottom water " at successive intervals, as derived from the observation of the water levels in the several holes.[1]

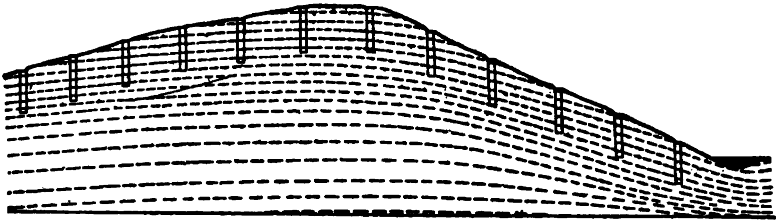

Fig. 42.—Percolation in clay land after heavyrain.

It will be seen that while at first the upper surface of the zone of saturation coincides with the surface of the ground, in falling it descends most rapidly on the highest ground, while at the lower levels the holes may remain full or overflowing; the drainage taking place sideways as well as vertically. The curved surface connecting the levels in the several holes gradually flattens, rapidly at first, then progressively more slowly; the water disappearing entirely, first from the holes lying highest, then successively from those at lower levels; those located in valleys or drainage channels remaining full until surface-water ceases to run in such channels. But even after liquid water has ceased to be visible in the holes, the descent of the water continues within that portion of the soil, tending (unless more rain should come before that time), to establish the condition of equilibrium as existing in the soil columns shown in the diagram on p. 205, chapt. 11; such as results from the capillary ascent of water from below, but having above it a column of soil of minimum water-content, of greater or less height according to the length of time allowed for the water to descend. This is a very common state of things during the long summer droughts in the arid region, when neither rain nor irrigation has added to the water supply in the soil for many months, and yet ordinary deciduous fruit trees mature their normal crops. Frequently, however, before this state of equilibrium is reached, evaporation from the surface so draws upon the water supply within the first few feet, as to reduce the soil to undersaturation at the lowest point of the descending column, so stopping farther descent and soon reversing the direction of the movement. The latter is the usual condition of scantily irrigated ground.

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[1] The exact record of these observations was unfortunately destroyed by fire the soil was a heavy clay, and it took ten days before the water disappeared from the lowest hole.

Ground or Bottom Water, Water Table.—During and after long-continued and abundant rains, the zone of supersaturation continues to descend until it finally reaches a more or less permanent level, varying somewhat from season to season, but on the whole usually definable for each region and locality; being the depth to which wells must be sunk in order to secure a fairly permanent water supply. This is called the water table, ground water, bottom water, or "first water."[1] The proportion of the rainfall that reaches the permanent water level varies enormously, of course, in different soils and at different times. With brief and moderate rains, in soils of high water-holding power and slow percolation, it may never reach the bottom-water level; this is very commonly the case in the arid regions. Where, as in the humid regions, rains are frequent or much prolonged, one half and even more may finally reach the permanent level; runoff and evaporation disposing of the balance.

Lysimeters.—For the determination of the amount of water percolating to given depths, water-tight receptacles called lysimeters are usually employed. The best way to establish such receptacles is to isolate a unit-area (usually a square meter) by digging all around it to the depth desired, then surrounding it with a metal sheet soldered tightly at the cut edges, and finally driving in a sharp-edged, stiff metal sheet so as to form the bottom when soldered to the upright walls; leaving on one side an outlet for the percolating water, which is then received into a measuring receptacle somewhat like a rain gauge.

Hall (The Soil, p. 75) states that at Rothamstead, where an average rainfall of 31.3 inches is distributed rather uniformly through the season, and where the soil is a moderately clayey loam, a little less than half percolates through 20 inches of soil, and about 45% through 60 inches.

Surface of Ground Water; Variations.—The surface of the

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[1] In contradistinction to other levels or "streams" of water which may usually be found lower down, separated from the first water by some impervious stratum of clay, hardpan or rock, and very commonly under sufficient pressure to rise somewhat higher than the point at which it was struck, owing to connection with higher-lying sources of supply. When such pressure is sufficient to cause an overflow at the surface of the ground, we have "Artesian" water as commonly understood.

water table, however, is rarely level except in level and very uniform ground, or after long periods of drought. The undulations of its surface conform, in general, to that of the ground surface, but are less abrupt; so that the water lies nearer to the surface in low than in high ground, as is indicated in the diagram above.

King[1] has shown, moreover, that the level of the ground water shows sensible variations due to increased or diminished barometric pressure, as well as to variations of temperature in the soil, which cause the air in the pores to expand or contract to a degree sufficient to bring about variations in the flow of springs and underdrains to the extent of 8 and 15% respectively, in conformity with the daily changes of temperature and pressure.

The Depth of the Ground Water most Favorable to Crops cannot be stated in a general manner, as it depends materially upon the nature of the crop, its root habit, and the nature of the soil. As has already been said, the amount of soil-moisture most favorable to plant growth is about half of the maximum it can hold; and this condition, as is shown in the table in chapter 11, p. 208, is reached about the middle of the maximum height to which the water can rise by capillarity from the water level. Below this point the access of air to the roots becomes too limited, and in case of continuous rains the root-ends would soon begin to suffer from want of aeration. On "sub-irrigated" land, therefore, which is generally considered desirable, crops must be carefully selected with respect to their root habits. Thus while alfalfa needs considerable moisture to do its best, its deep-rooting habit renders it undesirable when the ground water is at less than five feet depth; but red clover may be grown even with the water level at three feet.

In clayey soils root-penetration is always less than in sandy lands; and although in the former the capillary ascent of water goes higher than in the latter, yet its movement in clays is so much slower than in sandy materials that unless water is within comparatively easy reach, the plants may suffer from drought. Experience has long ago fixed the proper depth at which to lay underdrains limiting the rise of bottom water, at from three to four and a half or even five feet in clay soils; greater

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[1] Physics of Agriculture, p. 270.

depths are only exceptionally used, partly because the laying of drains then becomes too expensive.

A mass of four feet of clay-loam soil is commonly, then, considered as sufficient to supply the needs of a crop; it being understood that in the humid region at least, such soils are usually the richest in plant food, so that a deeper range of the root system is not called for. It is quite otherwise in the sandy soils of the same region, which being usually poor in plant food, must afford a deeper penetration in order that an adequate amount of the same shall be within reach of the roots. Sandy lands, then, should be deep in order to repay cultivation; and fortunately this is usually the case. But when this is otherwise; when for instance a sandy soil four feet in depth is underlaid by impervious clay, underdrains may be quite as necessary as in the clay lands; since the depth of actually available soil mass would otherwise be reduced to two or two and a half feet only, by the water stagnating on the clay surface and rising from 16 to 24 inches in the sand. Soils thus shallowed can with difficulty be maintained in good productive condition even by the most energetic fertilization.

Moisture supplied by tap roots.—In most cases, sandy lands do not require underdraining; and in them, root-penetration may reach to extraordinary depths in the case of certain plants, especially when tap-rooted. Thus the roots of alfalfa (lucern) are very commonly found to reach depths of twenty to twenty-five feet, and even sixty feet has been credibly reported for the same plant in the arid region. It is obvious that for such plants, a high level of bottom water is wholly undesirable, since they are enabled to obtain their moisture supply from great depths, and can thus utilize for their nutrition much larger soil-masses than can shallow-rooted plants.

Reserve of Capillary Water.—It must be remembered that it is not only, *nor usually*, the bottom water that snpplies moisture to plant growth; for all soils of proper texture for cultivation retain within them a certain amount of capillary moisture after the ground water has reached its permanent level (see this chap. p. 226), and when the tap or main roots are plentifully supplied with water, the upper and chief feeding roots draw but lightly upon the moisture within their immediate reach for the purpose of leaf evaporation. This fact can be plainly observed in the arid region, when on the advent of the summer drought, young plantlets whose tap roots have reached a certain depth continue to flourish and develop, while others practically of the same age, but slightly behind, quickly succumb, though the *feeding* roots of both may draw upon the same soil layer. It is especially in sandy soils that moisture is naturally thus conserved in the upper layers, because of the failure of the water to rise by capillary ascent so as to evaporate from the surface layer. It is often surprising to find a good amount of moisture in the sandy soils of desert regions at the depth of eight of eight or ten inches, when the surface is so hot as to scorch the fingers; and this moisture continues very uniformly to great depths, probably to bottom water lying twenty or more feet below the surface, which in such materials may readily by reached by tap-rooted plants such as the "sage-brush" (Artemisia tridentata), the saltbushes (Atriplex) and others.

Injurious Rise of Bottom Water resulting from Irrigation. —In the deep, pervious sandy lands of the arid region, especially where the rainfall is very low and can wet the soil annually only to two or three feet depth, the substrata are sometimes found to be barely moist to depths of thirty and forty feet, and the short-lived spring vegetation carries off during its growth all the moisture supplied by the winter rains. When such lands are subjected to irrigation and the ditches carrying the water are simply dug into the natural sandy land, the thirsty soil absorbs the water greedily, so that even a considerable volume of water makes but slow progress toward the farther end of the canals. Gradually, as the rapidity of absorption decreases, the diminution of flow becomes less sensible, but still the loss thus experienced may be a very considerable percentage of the whole supply. Thus in the Great Valley of California, as well as in portions of Wyoming (Bull, 61, p. 32), the permanent loss from seepage is in the case of some extensive irrigation systems estimated at fully 50 per cent. When such lands have a considerable slope, the injury commonly ends with the loss of the water, which in many cases is again gathered and utilized at a lower level. But when the lands have but a slight slope, the drainage may become so slow as to permit of the gradual rise of the seepage water in the substrata, until finally it may come to within a few feet of, or actually *to* the surface.

Consequences of the Swamping of Irrigated Lands.—The injurious consequences of this swamping of the irrigated lands may readily be imagined. The first effect is usually noted in the sickening or dying-out of orchards and vineyards, consequent upon the submergence of the deeper roots, which in such lands frequently reach to from fifteen to twenty feet below the surface. But even where pre-existing plantations are not in question, the shallowing of the soil- and subsoil-strata from which the plants may draw their nourishment, constitutes a most serious injury to the cultural value of the land. It has become unsuited to deep-rooted crops; and where the natural soil, alone, would have perpetuated fertility for many years, fertilization becomes necessary within a short time. The injury becomes doubly great when, as is frequently the case, the rising bottom water brings up with it to the surface soil the alkali salts which previously were distributed throughout many feet of substrata, frequently rendering profitable cultivation impossible where formerly the most luxuriant crops were grown.

Theoretically of course it is perfectly easy to avoid or remedy these troubles. It is only necessary to render the ditches water-tight by puddling with clay, cement, or otherwise. But the heavy cost of this improvement forms a serious obstacle to its adoption by the ditch companies who are not themselves owners of land. Thus, extensive areas of lands which when first irrigated were among the most productive, have in the course of eight or ten years become almost valueless to their owners, to whom legislation thus far affords but distant promise of relief; although the case seems in equity to fall clearly within the limits of the laws governing trespass.

Permanent Injury to Certain Lands.—In cases like those alluded to the remedy usually available for higher ground-water does not always afford relief, even when otherwise available. Long-continued submergence produces in many soils effects which cannot easily, if at all, be overcome by subsequent aeration. This is most emphatically true of soils containing a large proportion of ferric hydrate in the finely divided form in which it is usually present in " red " soils.

The first effect of the stagnation of water in such lands (as already explained in a former chapter (3, p. 45) is to set up a reductive (bacterial) fermentation of the organic matter of the soil, transforming the ferric into ferrous hydrate, which in the presence of the carbonic acid simultaneously formed, becomes ferrous carbonate, readily soluble in carbonated water. That this compound is poisonous to plant growth, has been stated (chap. 3, p. 46). The carbonates of lime and magnesia are simultaneously dissolved by the same, as is also calcic phosphate, the usual form in which phosphoric acid is present in the soil. Under the influence of partial aeration from the surface, the ferrous carbonate is slowly re-transformed into ferric hydrate, aggregated in the form of spots or concretions of "bog ore" (see chapter 5, p. 66). In this process the greater part of the phosphoric acid of the soil is also abstracted from its general mass and concentrated in the bog ore (chap. 5, p. 65), in which it is wholly unavailable to vegetation, and cannot be made available while in the ground, by any known process. The soil is therefore permanently impoverished in phosphoric acid; it is also deprived of its content of ferric hydrate, and is transferred from the class of "red" to that of "white" soils, well known everywhere to be unthrifty and to require early fertilization. Not only is this true, because of their almost invariable poverty in phosphoric acid, but also usually in lime, which like the iron, if not leached out, is aggregated into concretions in the subsoil, leaving the surface soil depleted of this important ingredient. The humus, also, is either destroyed or at least "soured" at the same time.

Reduction of Sulfates.—Should such a soil contain any considerable amount of sulfates, especially in the form of gypsum or calcic (or magnesic) sulfate, the reductive process results in the formation of iron pyrites (ferric sulfid, chap. 5, p. 75); while at the same time the soil is often sufficiently impregnated with sulfuretted hydrogen as to be readily perceived by the odor, or by the blackening of a silver coin. This is very commonly the case in seacoast marshes, where a hole made with a stick thrust into the mud will be found to give forth both carburetted and sulfuretted hydrogen, while a careful washing of the soil will reveal the presence of minute crystals of iron pyrites. Hence the need of prolonged aeration of marsh soils, effecting the peroxidation of the ferrous compounds, and the conversion of the pyrites first into ferrous sulfate, and subsequently into innocuous, yellow, insoluble ferric oxy-sulfate.

Ferruginous Lands.—The injurious effect of the swamping of ferruginous lands has been especially conspicuous in some of the irrigated rolling lands of the Sierra Foothills of California, where orchards planted in relatively low ground and in full bearing have succumbed to the poisonous effects of the ferrous carbonate formed in the subsoil, long before the water had risen so high that, had the trees been grown afterwards, they would have adapted their root system to the existing conditions and fared moderately well at least. Underdrainage of the lower lands is, of course, the only possible remedy for this state of things, although even then the root-penetration is much more restricted, and therefore natural fertility of much shorter duration, than would have been the case without the rise of the irrigation water.

It is thus clear that in the practice of irrigation, the liability of injury to the lower ground by "swamping" through the rise of the ground water should always be kept in view; that, in fact, irrigation and provision for drainage should always go hand in hand. The legal provisions facilitating the rights-of-way for irrigation ditches should be made equally cogent with respect to drainage.

CHAPTER XIII.

WATER OF SOILS (*Continued*).

THE REGULATION AND CONSERVATION OF SOIL MOISTURE.

In view of the commanding importance of an adequate supply of water to vegetation, the possible and available means of assuring such supply by utilizing to the best advantage both rainfall and irrigation water, require the closest consideration.

Loosening of the Surface.—The first thing needful, of course, is to allow the water free opportunity to soak into the soil, so as to moisten the land as deeply as possible. That to this end the surface should be kept loose and pervious by tillage, breaking up crusts that may have been formed by the beating of rains, has already been discussed. In the case of heavy clay soils, however, this alone is not always sufficient. The most effectual way to loosen the land to greater depths than can be reached by tillage, is by means of underdrains laid at the greatest depth that is practically admissible.

Effects of Underdrains.—That drain tiles laid for the express purpose of carrying off surplus water should help to conserve soil moisture, seems at first sight to be a paradox. Yet the explanation of the fact, which has been demonstrated by long experience, is not difficult. The effect is most striking in clay soils, for sandy soils are commonly naturally underdrained already.

In discussing the changes of volume which soils undergo in wetting and drying, the fundamental points in the premises have already been mentioned (see chap. 7, p. 112). Clay soils in drying shrink considerably, and re-expand on wetting, but rather slowly; moreover, some clays crumble when wetted *after* drying, while others, very plastic when wet, crumble on drying (see chap. 7, p. 116).

It follows that while a clay subsoil when kept permanently wet, will form a uniform, pasty, difficultly penetrable mass:

when subjected to frequent alternate wetting and drying, it becomes fissured and crumbly, so as to resemble in its texture a tilled soil. This frequent alternation of wetting and drying is precisely what, in the course of time, is brought about by underdrains; rendering clay subsoils pervious both to air and water. The consequence is that even heavy rains can be fully absorbed by the soil mass lying above the drains, the surplus draining off readily in a short time. Roots therefore can not only penetrate, but exercise their vegetative functions perfectly at the full depth of the drains. They are still at liberty to penetrate as much deeper as their demands for moisture may require; but the depth of four to four and a half feet is already so much greater than in the humid region would usually be reached by them in undrained clay soils, that commonly the moisture successively retained within that mass is as much as is required by them during the growing season. At the same time, their feeding roots are so far below the surface, that ordinary short droughts do not reach them at all; while the underdrains prevent any injurious stagnation of water around them. It need hardly be added that the entire task of cultivation is also greatly facilitated; not only because drained soils can be plowed within a few hours after the cessation of rains, as against the same number of days that would have to elapse in the undrained areas; but because tillage is easier, and less draft is required, even when it is carried to a much greater depth.

Underdrainage, then, must be counted as being among the most effective means both of utilizing the rainfall so as to prevent loss from runoff and injury from washing, and of creating a deep, loose, pervious soil mass, well adapted to root penetration as well as to the conservation of moisture; rendering possible timely tillage and cultivation, and early development of crops fully supplied with moisture and therefore secure against loss from drought. The safety and improvement of crops thus secured corresponds in the humid region to that brought about by the command of irrigation water in the arid countries. But it by no means follows that underdrainage can therefore be dispensed with in the latter, or irrigation in the former. Both have their proper place in both regions; but from special causes underdrainage, as has already been stated, should be widely used in irrigation countries to prevent the injuries otherwise but too likely to arise from over-irrigation (see chap. 12, p. 231).

Winter Irrigation.—In many regions where irrigation is desirable but not absolutely necessary in ordinary seasons, or where irrigation water is scarce in summer, much advantage is gained by insuring thorough saturation of the land during the latter part of winter, especially when spring or summer crops are to be sown. The not inconsiderable time required for water to reach its permanent level or the country drainage in most soils, often insures the retention of a certain surplus over what the soil can permanently hold, within the period when it can be utilized by growing crops; whose roots moreover are more likely to penetrate deeply in land where there is a steady increase of moisture as they descend, than when the contrary condition is encountered. The use of *winter flood-waters to saturate the land* is therefore in many cases the saving clause for a dry season.

METHODS OF IRRIGATION.[1]

The manner in which irrigation water is supplied to land and especially to growing crops exerts such a potent influence not only upon the welfare of the plants but also upon the condition of the land, that a brief discussion of this topic seems necessary.

The following methods are in use to a greater or less extent:

1. Surface sprinkling.
2. Flooding.
    A. By lateral overflow from furrows or ditches.
    B. By the "check" system.
3. Furrow irrigation.
4. Lateral seepage from ditches.
5. Basin irrigation.
6. Irrigation from underground pipes.

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[1] Only a general outline of the principles of this subject is given in this volume; special works must be consulted for working details. Among these the volume by King on "Irrigation and Drainage" gives probably the most comprehensive presentation of the subject for both humid and arid climates. Also bulletins of the U. S. Dep't of Agriculture.

Surface Sprinkling.—This method seems to be the closest imitation of the natural rainfall; and yet it is in practice about the most wasteful and least satisfactory of all. It is difficult of application on any large scale, from obvious causes; on the small scale, in gardens and on lawns, its disadvantages become amply apparent. As usually practiced, from a rose spout or spray nozzle, the water falls much more abundantly than in the case of any desirable rain, within the short time allowed by the patience of the operator. If continued for a sufficient length of time to soak the soil to the desirable depth, it compacts the surface of the ground so as to render subsequent tillage indispensable. To avoid this, amateur gardeners usually restrict the time of application, repeating the same at frequent intervals, sometimes daily. The result is that the very slight penetration of the water either fails to reach the absorbent roots, so that it is of little use to them, and is evaporated by the next day's sun or wind; or else it tends to draw the roots close to the surface, where, unless the application of water is actually made daily, they are sure to suffer from the first intermission of the daily dose. In actual practice the sprinkling method is therefore both inefficient and wasteful of water, and exposes the plants to grave injury from any cessation of the water supply.

Flooding presupposes land either level or only slightly sloping naturally, or rendered so artificially; usually by means of the plow and horse scraper.

Flooding by lateral overflow from large furrows, or ditches, is very commonly practiced where the water supply is abundant and large areas, such as alfalfa or grain fields, are to be irrigated. The overflow is regulated by portable check-boards, proceeding from the highest points to the lowest, and leaving each temporary dike in place until the ground is adequately soaked or the water reaches the next furrow below. In heavy ground the operation may have to be repeated to insure proper depth of percolation.

Check flooding necessitates more careful leveling, and the throwing up of small dikes, either temporary or permanent. The costliness of the earth-work restricts the use of this method materially, and the inconvenience caused in tillage by the dikes is objectionable, especially in large-scale culture. For the case of alfalfa fields, which remain permanently set for a number of years, it is however the largely preferred method. In the case of field cultures, the consolidation of the surface that follows flooding on the heavier soils renders subsequent tillage necessary in all but very sandy soils; and hence it should always *precede* broadcast sowing.

One disadvantage of the surface-flooding system is the slow penetration of the water caused by the resistance of the air in the soil to downward displacement; its buoyancy acting directly contrary to the percolation of the water. In close-grained, heavy soils this objection is very serious, on account of the loss of time involved when the irrigator's time is limited. On sandy lands the air bubbles up quite livelily at first, but this soon ceases and the air is compelled to escape sideways as best it can.

Furrow Irrigation.—By this method it is intended to soak the land uniformly by allowing the water to flow through furrows drawn 3 to 8 feet apart, with a gentle slope from the supply or head ditch; the flow being continued until the water has reached the far end of the furrows, or longer according to the nature of the soil, especially if another ditch to receive the surplus flow lies below. The furrows should subsequently be closed by means of the plow or cultivator; but even if left open they are much less a source of waste by evaporation than would be a flooded surface. The water thus, in the main, soaks downward and only reaches the surface by capillary rise, so that the land between the furrows is not sensibly compacted when the furrows have been made deep enough. Evidently this is a much more rational procedure than surface flooding, as it tends to leave most of the surface in loose tilth, while penetrating to much greater advantage, because of the ready escape of the air from the soil. It is the system naturally and almost exclusively used in truck gardens and orchards, and generally where crops are grown in drills or rows sufficiently far apart to permit of cultivation.

The figure annexed[1] shows the manner in which water sinks and spreads from furrows of various depths and widths,

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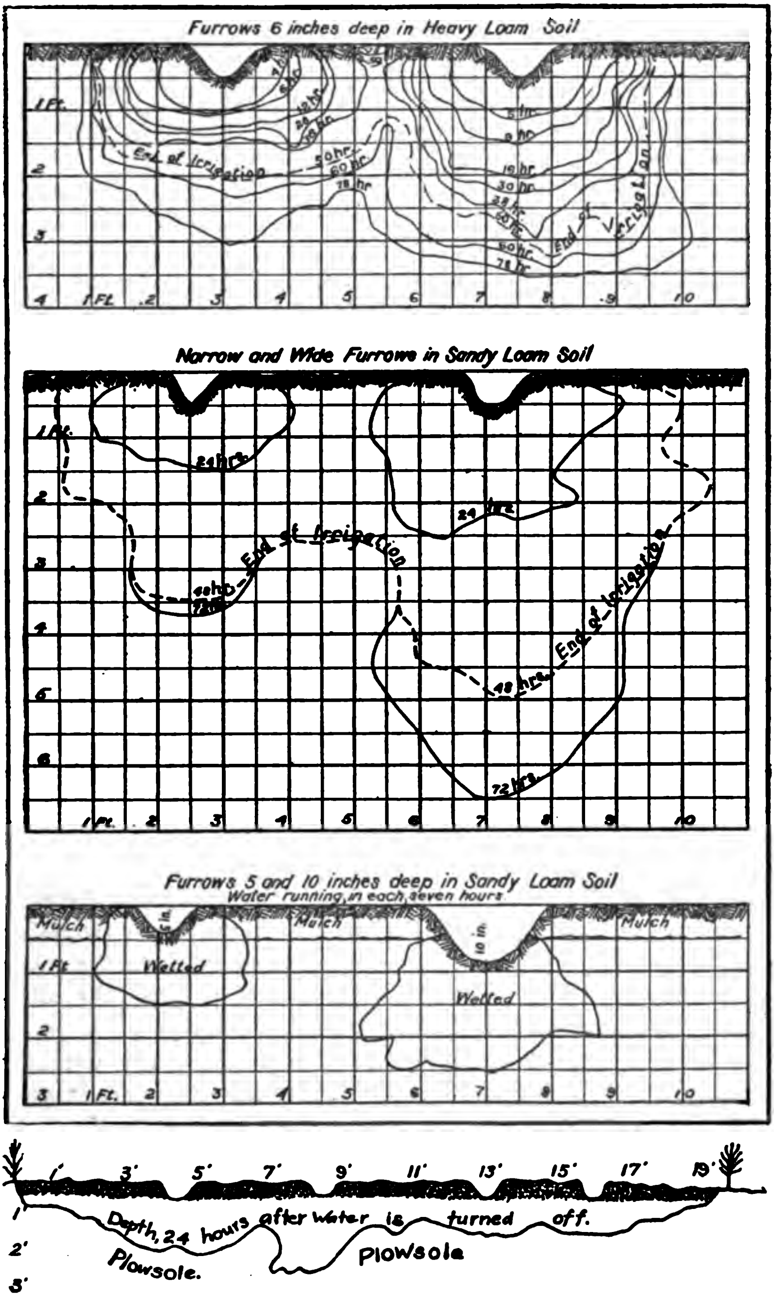
[1] **Published by permission of the Department.**



Furrows 6 inches deep in Heavy Loam Soil

Narrow and Wide Furrows in Sandy Loam Soil

Furrows 5 and 10 inches deep in Sandy Loam Soil
Water running in each seven hours

FIG. 43.—Profiles of Water penetration in Furrow Irrigation.

as actually observed in the work of the Irrigation Division of the U. S. Dep't of Agriculture, under the direct supervision of Prof. R. H. Loughridge of the California Station. The mode of percolation is shown for two soils, a heavy loam and a sandy one, both in the vicinity of Riverside, Cal.

The upper section shows the variation in penetration in one and the same soil with the same kind of furrow, the broken line indicating the cessation of the flow in the furrows; after which there was a still farther penetration of the water to from 6 to 9 inches deeper.

The second section from above shows the percolation of the water respectively in wide and narrow furrows of the same depth. It is evident at a glance how much more effective is the wide furrow in utilizing the limited time during which the irrigator usually has the flow at his command.

The third section shows several practically important points in favor of the wide and deep instead of narrow and shallow furrow. It is seen that in doubling the width and depth, the penetration has also nearly doubled. Moreover, it is seen that in the deep furrow the water has not in the course of seven hours reached the surface at all, being still six inches away; so that in view of the diminishing ratio of capillary ascent, it probably would not have reached the edge of the furrow, at the surface, in less than thirty hours. Thus all surface evaporation, which oftentimes causes the loss of 50 % of the water entering the shallow furrows, would be prevented; and a dry furrow-slice might be turned into the furrow immediately after the cessation of the water-flow, effectually obviating the need of subsequent tillage also. The cost of the latter, together with the saving in water, and increased efficiency of the water by deeper penetration, will much more than offset the additional cost and trouble of plowing deeper furrows.

There is therefore every reason for doing away with the wasteful, easy-going practice of irrigating in numerous shallow furrows, by which the irrigator loses up to half of the water paid for, by evaporation; is compelled to wait for the soaked surface to dry before being able to turn back a furrow-slice into the furrows to prevent the drying-out of their moisture; and by losing penetration of the water, is obliged to irrigate again within a much shorter time than will be necessary if deep-furrow irrigation be used.

A similar experiment with deep and shallow furrows was made at the Southern California station near Pomona in 1901, as reported in Bulletin 138 of the California Station. The results as far as they went were precisely similar, and upon the basis of these the writer earnestly advocated deep-furrow irrigation, and had the satisfaction of seeing it strongly approved by orange-growers at Riverside and elsewhere, by putting it into practice.

In addition to the saving and better utilization of the water used, this mode of application has the advantage of preventing the roots from coming too near the surface; it will also largely eliminate "irrigation hardpan" or plowsole.

The results produced by long-continued shallow plowing and irrigation in shallow furrows is well illustrated in the last of the irrigation profiles, which shows the observations made on the same land as the others, but where rational cultivation and deep-furrow irrigation had not yet been introduced. It will be seen that after applying, and of course paying for, the water for three days, its average penetration was only about eighteen inches; so that the trees of the orchard received very little benefit, and were supposed to be needing fertilization when in fact they were simply suffering from lack of water at the lower roots.

One somewhat unexpected point is shown by these diagrams, viz., the slight sidewise penetration of the water; the wetted areas having a nearly vertical lateral outline. This means, of course, that unless the furrows run very near the trees of an orchard, the soil immediately beneath the trees will remain dry; thus inducing the roots to spread sideways and losing depth of penetration and soil. It will be noted especially in the lower figure that here again the deep furrow offers a material advantage over the shallow, the sidewise spread being much more pronounced than in the shallow furrow alongside.

Distance Between Furrows and Ditches.—The distance between the furrows must, of course, be proportioned to the readiness with which the water penetrates, being less as the land is of closer texture. The distance between head ditches practiced in California, but has now been mostly abandoned for furrow irrigation. The latter has been adopted partly because it requires a great deal less hand-labor, partly under the impression that the whole of the soil of the orchard is thus most thoroughly utilized; partly also because of the injurious effect upon trees produced at times by basin irrigation.

The explanation of such injurious effects is, essentially, that *cold* irrigation water depresses too much the temperature of the earth immediately around the roots, and thus hinders active vegetation to an injurious extent, sometimes so as to bring about the dropping of the fruit. This of course is a very serious objection, to obviate which it might be necessary to reservoir the water so as to allow it to warm before being applied to the trees.[1] In furrow-irrigation the amount of soil soaked with the water is so great that the latter is soon effectually warmed up, besides not coming in contact too intimately with the main roots of the tree; along which the water soaks very readily when applied to the trunk, thus affecting their temperature much more directly. It is for the farmer to determine which consideration should prevail in a given case. If the water-supply be scant and warm, the most effectual use that can be made of it is to apply it immediately around the tree, in a circular trench dug for the purpose. When on the contrary, irrigation water is abundant and its temperature low, it may be preferable to practice furrow irrigation, or possibly even flooding.

As to the supposed more complete use of the soil under the latter two methods, it must be remembered that while this is the case in a *horizontal* direction, if irrigation is practiced too copiously under the shallow-furrow system, it may easily happen that the gain made horizontally is more than offset by a corresponding loss in the *vertical* penetration of the root-system. This is amply apparent in some of the irrigated orange groves of southern California, where the fine roots of the trees fill the surface soil as do the roots of maize in a corn field of the Mississippi States; so that the plow can hardly be run without turning them up and under. In these same orchards it will often be observed, in digging down, that at a depth of a few feet the soil is too water-soaked to permit of

[1] See below, chap. 17.

the proper exercise of the root-functions, and that the roots existing there are either inactive or diseased. That in such cases frequent irrigation and abundant fertilization alone can maintain an orchard in bearing condition, is a matter of course; and there can be no question that a great deal of the constant cry for the fertilization of orchards in the irrigated sections is due quite as much to the shallowness of rooting induced by over-irrigation, as to any really necessary exhaustion of the land. When the roots are induced to come to and remain at the surface, within a surface layer of eighteen to twenty inches, it naturally becomes necessary to feed these roots abundantly, both with moisture and with plant-food. This has, as naturally, led to an overestimate of the requirements of the trees in both respects. Had deep rooting been encouraged at first in the deep soils of the southern "citrus belt," instead of over-stimulating the growth by surface fertilization and frequent irrigation, some delay in bearing would have been compensated for by less of current outlay for fertilizers, and less liability to injury from frequently unavoidable delay, or from inadequacy, of irrigation.

Irrigation by Underground Pipes.—Where economy in the use of irrigation water is a pressing requirement, its distribution through underground pipes affords the surest mode of accomplishing that end, in connection with the application of the water in accordance with the principles just discussed. The enormous saving of water effected by its conveyance in cement-lined ditches or concrete pipes, as compared with earth ditches, if additionally combined with its application to individual trees or vines, presents the maximum of economy that can be effected. The actual use of this method is unfortunately limited in practice by the high first cost of piping; but as its use renders unnecessary the digging of basins and plowing of furrows and their subsequent closing-up, it is when once established by far the cheapest system, both as to the use of water and of labor.

The best results of this system are undoubtedly achieved by the use of iron pipes for the distribution in field and orchard, whatever may be the material used for the main conduits. The use of concrete and tile in small sizes proves in the end very expensive, because of frequent breakage, and leakage due to varying pressure in the supply pipes or reservoirs; as well as from even slight earthquake tremors, undermining by water or by the burrowing of animals, and many other accidents which do not affect an iron pipe system. The pipes must in any case, of course, be laid deep enough to be out of reach of the deepest tillage; therefore not less than one foot, and preferably eighteen inches. A proper construction of the outlets, permitting of exact regulation of the flow and ready operation from above ground, as well as preventing their being clogged by earth, rust, roots or burrowing animals, insects etc., is of course of the greatest importance. A variety of devices for this purpose is already on the market.

QUALITY OF THE IRRIGATION WATER.

Saline Waters.—Considering the large amount of water annually used in irrigation, among the most needful precautions to be observed by the irrigator is in the testing of the quality of his water-supply. First among the points to be noted is the possible content of soluble "alkali" salts. While in most cases what is called the "rise of the alkali" is due to the salts already contained in the soil and subsoil, in but too many the evil is either brought about, or greatly aggravated, by the excessive saline contents of the water used in irrigation. The effects of the use of saline irrigation water (containing in this case about 100 grains per gallon, or 1700 parts per million) are shown in the accompanying plate. The predominant ingredients of these alkali salts were common salt and carbonate of soda. In the lands near Corona, Cal., where this case was observed, the original alkali-content of the soil was about 2500 pounds per acre in four feet depth, and had been just quadrupled, with the results shown; viz., complete defoliation of the orange trees, while on the same land, where the trees had been irrigated with good artesian water, the orchard was in fine condition.

Limits of Salinity.—It is not easy to assign a definite limit of mineral content beyond which water should be considered unfit for irrigation purposes; partly because of the differences in the kind of the mineral salts, partly because the nature of the soil and the amount of water at command, materially influence its availability.

Fig. 44.—Orange Trees Irrigated with Artesian Water.

Fig. 45.—Lake Elsinore Water, Three Years.

Forty grains per gallon is usually assigned as the limit for potable as well as irrigation waters. But if most or the whole of such mineral contents should consist of the carbonates and sulfates of lime and magnesia, the water while unsuitable for domestic use may be perfectly available for irrigation, since these salts are either beneficial or harmless in the amounts likely to be introduced by the water. But if most or the whole of such forty grains should consist of " alkali salts " proper, viz., the sulfates, chlorids and carbonates of potash and soda, or if they should contain even small amounts of the chlorid and magnesium, they might render the water either wholly unsuitable for irrigation, or if used it would be needful to take the mineral content into consideration, by regulating its application accordingly.

It has been found in California that practically the upper limit of mineral content for irrigation water *under the ordinary practice* lies below seventy grains per gallon in *all* cases; for when this strength is reached, even though such water may bathe the roots of almost any plant with impunity, yet accidental concentration by evaporation is so certain to happen, that injury to crops is practically almost unavoidable.

In South Dakota and other parts of the American semi-arid region, waters containing seventy grains and even more of alkali salts per gallon are annually used during the short irrigation season. This can be done harmlessly because the aggregate amount used is only small, and the more abundant rainfall of that region annually washes the salts out of the soil. But where almost the full amount of water required by crops must be supplied by irrigation, the total amount of salts thus introduced would speedily render the land uncultivable.

According to the observations of Means and other explorers[1] of the U. S. Dep't of Agriculture, waters of much higher mineral content are used for irrigation both in Egypt and in the Saharan region, some going as high as 8000 parts per million, or 214 grains per gallon. The cultivators are said to be very skilful in the use of these waters, applying them only to plants of known resistance, and in certain ways. These ways include doubtless a good deal more time and pa-

[1] Bull. No. 21, Bureau of Soils; also circular No. 10, ibid.

tience than American irrigators are ordinarily willing to bestow upon their work. Much depends of course not only upon the character of the salts in the water, but also upon the long experience had in the old irrigation regions.

Mode of using Saline Irrigation Waters.—The fact that abundant growths of native as well as cultivated plants may sometimes be seen on the margins of "alkali lakes" where water of over a hundred grains of mineral salts per gallon continuously bathes the roots, while the same plants perish at some distance from the water's edge, points the way to the utilization, in emergencies, of fairly strong saline waters; viz., by the prevention of their concentration to the point of injury *by evaporation.* It is clear that when such waters are used sparingly, so as to penetrate but a few feet underground, whence the moisture re-ascends for evaporation at the surface, a few repetitions of its use will accumulate so much alkali near the surface as to bring about serious injury. If, on the other hand, the water is used so abundantly that the roots may be considered as being, like the marginal vegetation of alkali lakes, bathed only by water of moderate strength, no such injury need occur; and what does accumulate in consequence of the inevitable measure of evaporation occurring in the course of a season, may be washed out of the land by *copious winter irrigation.*

This, of course, presupposes that the land, as is mostly the case in the arid region, is readily drained downwards when a sufficiency of water is used. When this is not the case, *e. g.*, in clay or adobe soils, or in those underlaid by hardpan, waters which in sandy lands could have been used with impunity, may become inapplicable to irrigation use.

Apparent Paradox.—The prescription to use saline waters *more abundantly* than purer ones, in order to avoid injury from alkali, though paradoxical at first sight, is therefore plainly justified by common sense as well as by experience, in pervious (sandy) soils; while in difficultly permeable ones, their use may be either wholly impracticable, or subject to very close limitation.

Sometimes the alternate use of pure and salt-charged water serves to eke out a too scant supply of the former. But in all such cases, close attention to the ***measure*** of water that will wet the soil to a certain depth, and "eternal vigilance" with respect to the accumulation of alkali near the surface, must be the price of immunity from injury. In all cases the farmer should know how much of alkali salts he introduces into his land with the irrigation water, and watch that it does not approach too closely, or exceed, the tolerance of his crops for alkali salts, as given in chapter 26.

Use of Drainage Waters for Irrigation.—When lands charged with alkali salts are being reclaimed by drainage, the question sometimes arises whether the drainage-water may not be used for irrigation, lower down. This of course depends entirely upon the amount of alkali in the water, the nature of the lands to be irrigated, and the manner of applying it. In the Fresno drainage-district of California it has been shown that some of the drainage-water contains not more than 25 to 30 grains per gallon of objectionable salts, and such waters could of course be used on pervious lands with the precautions above noted.

"Black Alkali" Waters.—As regards, however, waters containing any large proportion of carbonate of soda, it must be remembered that even very dilute solutions of salsoda serve to puddle the soil and thus render it difficultly tillable. When such waters are used it is necessary to forestall injury either by the use of gypsum in the reservoir or ditch, or by annually using on the land a sufficient amount of gypsum to transform the carbonate of soda into the relatively innocuous sulfate.

Variations in the Saline Contents of Irrigation Waters.—When irrigation waters are derived from deep wells, there is little if any variation of their saline contents to be expected, and a single analysis will serve permanently. But in the case of relatively shallow wells, from which the water must be raised by pumping, it not unfrequently happens that after a series of seasons of short rainfall, saline waters are brought up by the pump and may seriously injure crops and orchards. Again, in the case of streams and rivers whose flow becomes very small in summer, the saline content may increase to several times the amount carried at the time of high water. Both kinds of cases occur in southern California, in Arizona,[1]

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[1] Bull. Ariz. Exp't Sta. No. 44.

New Mexico and other states of the arid region. The Gila, Pecos and upper Rio Grande are cases in point, and to a certain extent the Colorado of the West.

Muddy Waters.—In the latter as well as other streams of Arizona, there is another point which sometimes creates difficulties to the irrigator, together with some current expense. It is the amount of silt or mud carried by the water, which while it is a benefit to the land over which it is spread, (" warping ") as in the classic case of the Nile, often clogs the irrigation ditches to such an extent as to cause considerable inconvenience and expense in cleaning them out. This is especially the case in the streams draining pasture lands that have been overstocked, and where the destruction of the natural herbage allows the rain water to run off rapidly, at first forming runlets and then gullies and ravines that originally were simply cow-paths leading toward the watering places.[1] The devastation of lands thus caused in Arizona is almost as great as that which has occurred in the Cotton states, as mentioned above chap. 12, p. 217.

These variations in the character of the irrigation water must of course be watched by the farmer who does not receive directly from mountain streams, or from deep artesian wells water known to have a constant content of saline matter.

THE DUTY OF IRRIGATION WATER.—The amount of water thought to be needed for the production of satisfactory crops varies widely in different regions, ranging all the way from about two feet to as much as eight annually, within the United States; while in the sugar-cane fields of the Hawaiian Islands as much as three inches per week, or over twelve acre-feet in the course of the year, have been thought to be beneficial, if not absolutely required for the best crop results.

As has been stated above (chap. 12, p. 215), the rainfall limit below which irrigation becomes, if not absolutely essential, at least a highly desirable condition for the safety of crops, is usually assumed to lie at about 20 inches (500 milimeters). This general statement is, however, subject to material modification according to the manner in which the rainfall is distributed. Thus in central Montana with 24 inches of rainfall distributed throughout the year, irrigation is indis-

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[1] Bull. Arizona Exp't Station Nos. 2, 38.

pensable; while in the Santa Clara valley of central California, with an average rainfall of 15 inches falling through the winter and spring, the growth of all ordinary field crops has for fifty years not failed oftener than is commonly the case in the humid region of the North Central states. This is because in California the winter and spring are the growing seasons, while the rainless summers do not stand in the way, for crops are already harvested; and the deep rooting of trees and vines provides these with the needful moisture from the depths of the substrata (see chap. 10, pp. 163 to 173).

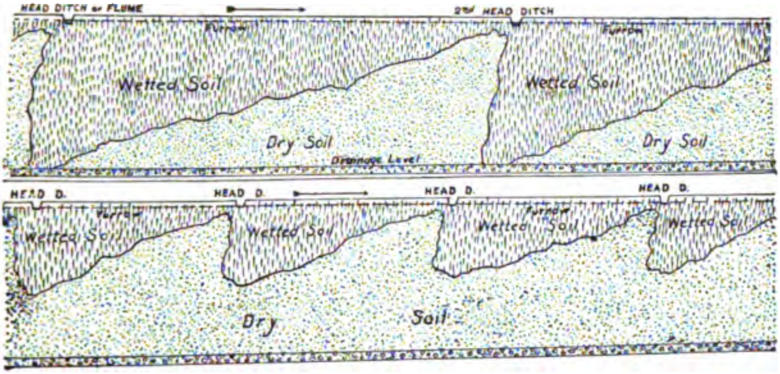
It would thus seem that twenty inches of irrigation water properly applied ought to be sufficient for all purposes, when added to the natural rainfall, which is rarely entirely absent. Yet in actual practice less than 24 acre-inches is rarely used, and much more is the rule; 72 to 96 ins. being sometimes used in Arizona. Evidently enormous losses occur in practice, and it is of the utmost importance to discover the causes of these.

Causes of Loss.—Since irrigation water is commonly measured at the distributing weirs, loss from seepage and evaporation on the way to the fields is an obvious source of an overestimate of the water actually supplied to the farmer. In sandy districts the loss thus incurred is reliably estimated at nearly 50% in many cases. The apparent duty of the water is thus at once reduced to half its effect, and four instead of two feet of water are supposed to have been used, and are charged for.

Evaporation resulting from surface flooding or use in shallow furrows may, again, cause the loss of from 30 to 50% of the water that actually reaches the land; so that in the latter case, between seepage and evaporation the irrigator may lose the effect of three-fourths of the water he pays for.

Loss by Percolation.—Finally, the water may be wasted on the land itself in leachy soils by over-use, *i. e.*, it may percolate to a large extent beyond the reach of the roots when the flow is continued too long; as will always be the case when the head (supply) ditches are laid too far apart, so that the water may be wasting into the country drainage just below the upper ditch long before the water in the furrow reaches the lower one; as illustrated in the upper one of the subjoined diagrams.

That this will not happen when the head ditches are nearer together, is shown in the lower diagram.



FIGS 46, 47.—Diagram showing loss by percolation when head ditchers are too far apart.

The means of avoiding the mechanical losses have already been discussed, and may be summarized thus: tightening of leaky ditches; use of water in deep furrows; and ascertaining the rapidity of percolation (see p. 242) so as to obtain a proper gauge for the time during which water should run, and for the distances at which head ditches or furrows should be placed.

The importance of thus diminishing the losses of water is obvious when it is considered that if the duty of water can be reduced to twenty instead of forty or fifty acre-inches, twice the area can be irrigated with the same amount of water, or the cost of water correspondingly reduced. It should be noted that when the land is leachy it may be pure waste to continue the flow beyond a few hours; but the irrigation must then be more frequently repeated.

EVAPORATION.

Alongside of and supplementary to the best possible utilization of the rainfall and irrigation water, the prevention of unnecessary evaporation has to be considered. Evaporation from the soil's surface implies not only unnecessary loss of water that should have remained for the use of the crop, but also the depression of temperature which, as a rule, is unfavorable to the best development of vegetation. It is only in case of extreme stress from hot, drying wind that such evaporation and the consequent depression of the temperature of the surface soil can be of advantage to the farmer.

The amount of water evaporating either from a water-surface, or from a wet or moist soil, varies greatly according to the climatic conditions, and the state of the weather; also according to the condition of the soil-surface. There are damp climates, and days or periods when, the air being nearly saturated with moisture, evaporation even from a water-surface will be almost insensible. On the other hand, with dry air and a high temperature, enormous quantities of water may be evaporated in the course of a day. The evaporation from water-surfaces interests deeply those who supply, as well as those who are supplied with, water from storage reservoirs; evaporation from the soil-surface interests deeply all farmers, and more especially irrigators whose water-supply is scanty, or is paid for by them by measurement. Light rains, as well as light surface irrigations, may at times evaporate almost wholly without any effect save a lowering of the temperature of the soil. In the case of snow, it is a well-known fact in the northern arid regions that a light snowfall may in winter evaporate entirely without imparting any liquid moisture to the soil. A loss of 50% of the water actually brought upon land by surface irrigation is of common occurrence in some portions of the irrigated region.

The dependence of evaporation upon air-temperature under conditions otherwise identical, is well illustrated by the experiments made in 1904 by S. Fortier[1] on the Experiment Station grounds at Berkeley, California, at a time when under the influence of the sea breeze the average saturation of the air might be assumed at about 70%. The tests were conducted in six tanks sunk into the ground so as to place the water-surfaces on a level with it, and the water-temperatures were maintained in four of the tanks by means of ice or heating lamps. The results are shown in the following table:

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[1] **Progress Report on Coöperative Irrigations in Calif.; Cir. No. 56, Office Exp't Stations.**

SUMMARY OF AVERAGE WEEKLY LOSSES BY EVAPORATION, WITH VARYING TEMPERATURES OF WATER, AT BERKELEY, CAL., IN JULY AND AUGUST, 1904.

Temperature of water.	Weekly evaporation.
Degrees Fahrenheit:	Inches.
55.5	0.42
62.0	0.77
69.2	1.54
80.1	3.08
89.2	3.92

A farther illustration is given in the subjoined table, showing maxima and mimima of monthly evaporation, as well the totals of one (seasonal) year, in three California localities where the air-saturation is considerably below that at Berkeley, ranging in summer from 50% to 20% and even less (at Calexico in the Colorado desert):

SUMMARY OF EVAPORATION-LOSSES FROM WATER-SURFACES, AT POMONA, TULARE, AND CALEXICO, CAL., FROM JULY 1, 1903, TO JULY 31, 1904.

	Pomona.		Tulare.		Calexico.	
	Month.	Inches.	Month.	Inches.	Month.	Inches.
Maximum	Aug. 1903	9.07	July 1903	12.34	July 1903	14.48
Minimum	Feb. 1904	2.57	Jan. 1904	1.46	Jan. 1904	4.39
Totals for year	....	66.92	....	74.68	....	108.23

Of these three stations, Pomona is located within reach of the ocean winds, but distant 25 to 30 miles from the shore. Tulare is situated in the upper San Joaquin valley, far in the interior; Calexico is in the southern part of the Colorado desert, with extremes of temperature ranging from 13° Fahr. in winter to 120° in summer.

Evaporation in Different Climates.—The following table conveys some general data regarding average evaporation from water-surfaces in different climates. Evaporation from the soil-surface depends largely, of course, upon the mechanical condition of the surface, the extent to which it is wetted, and the rapidity with which moisture will be supplied from the subsoil as the surface dries. A field plowed into rough furrows will evaporate more water than when harrowed, because of the larger surface exposed; and a harrowed field moderately compacted by rolling will lose less water by evaporation than when un-rolled, other things being equal. On the other hand, a thoroughly compacted surface, even if suffering less loss at first than a plowed or harrowed field, will continue to lose moisture longer by withdrawing it from the substrata by its superior capillary suction; while a loose surface, once dried out, will prevent farther loss from the subsoil very effectually, as stated below.

TABLE SHOWING EVAPORATION, FROM WATER-SURFACE EXPOSED IN SHALLOW TANKS, NEAR WATER OR GROUND SURFACE.

	Years.	Inches.
Rothamsted, England	9	17.80 (16.6 to 18.4)
London, "	14	20.66
Oxford, "	5	31.04
Munich, Germany	?	24.00
Emdrup, Denmark	10	27.09
Cambridge, Massachusetts	1	56.00
Syracuse, New York	1	50.20
Logan, Utah	1	52.39
Tucson, Arizona	1	75.80
Fort Collins, Colorado	11	41.00
Fort Bliss, Texas	1	82.70
San Francisco, California	....	45 to 50
Sweetwater Reservoir, San Diego, California	1	57.6
Peking, China	?	38.80
Demerara, South America	3	35.12
Bombay, East India	5	82.28
Petro-Alexandrowsk, West Turkestan	?	96.40
Kimberley, South Africa	?	98.80
Alice Springs, South Australia	?	103.50

This table, the data for which are taken from various sources, exhibits clearly the enormous variations in evaporation in different countries, and even in localities not very remote from each other. The low evaporation near London is doubtless due to its foggy and hazy atmosphere, but it is not clear why Rothamsted should show so low an evaporation compared with Oxford. Tropical Demerara stands nearest to Oxford in its evaporation; Bombay indicates its location on the hot and arid west coast of India, despite its nearness to the sea. The inland localities in the desert regions of South Africa, Australia and Western Turkestan, show how enormous may be the losses from evaporation of irrigation water, unless the latter is applied with special care for their prevention. Thus, with the wasteful methods of irrigation prevailing in portions of the American arid region, it is certain that in many cases 50% and more of the water evaporates before it reaches the crops.

Evaporation from Reservoirs and Ditches.—The evaporation from water-surfaces especially may, in many cases, exceed the rainfall of the year, so as to materially diminish the available water-supply in reservoirs. Thus the annual evaporation from the reservoir-lakes forming part of the water-supply of the city of San Francisco, ranges from 40 to 50 inches, while the rainfall averages less than 24 inches. Were it not, then, for the prevention of evaporation by a covering of dry earth during summer, no moisture would remain in the ground to sustain vegetation. In the cool coast climate of Berkeley, Cal., directly opposite the Golden Gate and subject to its summer fogs, evaporation from a water-surface maintaining the average climatic temperature of 60°, was found to be ¾ inch during the month from the middle of July to the middle of August, 1904. But at the high temperatures and low degree of air-saturation prevailing in the great interior valley, or in the Colorado desert, the evaporation from water-surfaces is enormously increased, exceeding even the figure given in the table for Bombay. Hence the great importance of preventing all avoidable evaporation, particularly in the use of irrigation water.

Prevention of Evaporation; Protective Surface Layer.—The loose tilth of the surface which is so conducive to the rapid absorption of surface-water, is also, broadly speaking, the best means of reducing evaporation to the lowest possible point. For while it is true that the floccules of well-tilled soil permit of the ready access of air, and therefore of evaporation, it is also true that these relatively coarse compound particles are incapable of withdrawing capillary moisture from the denser soil or subsoil underneath; just as a dry sponge is incapable of absorbing any moisture from a wet brick, while a dry brick will readily withdraw nearly all the water contained in the relatively large pores of the sponge (see chap. 11). A layer of loose, dry surface-soil is therefore an excellent preventive of evaporation of the moisture from soils, and may be regarded as the natural and most available means to be used by the farmer, both for the prevention of evaporation and to moderate the access of excessive heat and dryness to the active roots.

As regards the desirable thickness of this protective layer of tilled surface-soil, it should be kept in mind that in the humid region, where rain can be expected at intervals of from one to three weeks, the feeding roots may usually be found within a few inches of the surface; while in the arid region, where irrigation is practiced at long intervals or sometimes not at all, so that no water enters the soil oftener than from two to six months, the roots necessarily vegetate at lower depths, and hence the protective surface-layer can, and should be, of greater thickness, to prevent the penetration of excessive heat and dryness during the long interval.

The failure to appreciate this necessary difference often leads to heavy losses on the part of newcomers to the arid region, who in this as in other respects are apt to follow blindly the precepts familiar to them in the East, until taught better by sore experience. In the East and Middle West a depth of three inches is considered the proper one for the protective surface-layer; and in the case of maize even this is considered excessive in many cases. In the arid region this depth should be at least doubled where irrigation is not practiced at least every four to six weeks; and in some sandy soils even seven and eight inches is not too much for effective protection.

Illustrations of Effects of Surface Tillage.—The efficacy of loose surface tilth in preventing evaporation, as compared with mere superficial scratching or with the total omission of cultivation, is well exemplified in a series of investigations conducted on this subject during the extremely dry season of 1898, by the California Experiment Station; the seasonal rainfall having during that year been on an average from one-third to one-half only of the usual amount, so as to test to the utmost the endurance of all growing plants. Some of the details of this investigation have been given above (p. 214) in connection with the question of moisture requirements of crops. Loughridge[1] also investigated the moisture conditions in adjacent orchards differently treated in cultivation. In one of these cases two orchards of apricots were separated only by a lane, and the soil identical; but one owner had omitted cultivation, while the other had cultivated to an extra depth in view of the dry season apparently impending. The results are best shown by the plates below, showing representative trees and the annual growth made by each. The table annexed shows the differences in the moisture-content of the two fields to the depth of six feet, in July:

MOISTURE IN CULTIVATED AND UNCULTIVATED LAND.

Depth in soil.	Cultivated.		Uncultivated.	
	Per cent.	Tons per acre.	Per cent.	Tons per acre.
First foot..............	6.4	128	4.3	86
Second foot.......	5.8	116	4.4	88
Third foot.............	6.4	128	3.9	78
Fourth foot............	6.5	130	5.1	100
Fifth foot..............	6.7	134	3.4	68
Sixth foot........	6.0	120	4.5	90
Total for six foot.......	6.3	756	4.2	512

The difference of 244 tons per acre of ground shown by the analyses is quite sufficient to account for the observed difference in the cultural result. The cause of this difference was that in the *uncultivated* field there was a compacted surface-layer of several inches in thickness, which forcibly abstracted the moisture from the substrata and evaporated it from its surface; while the loose surface soil on the *cultivated* ground was unable to take any moisture from the denser subsoil.

The cultural results were that on the cultivated ground the trees made about three feet of annual growth, and the fruit

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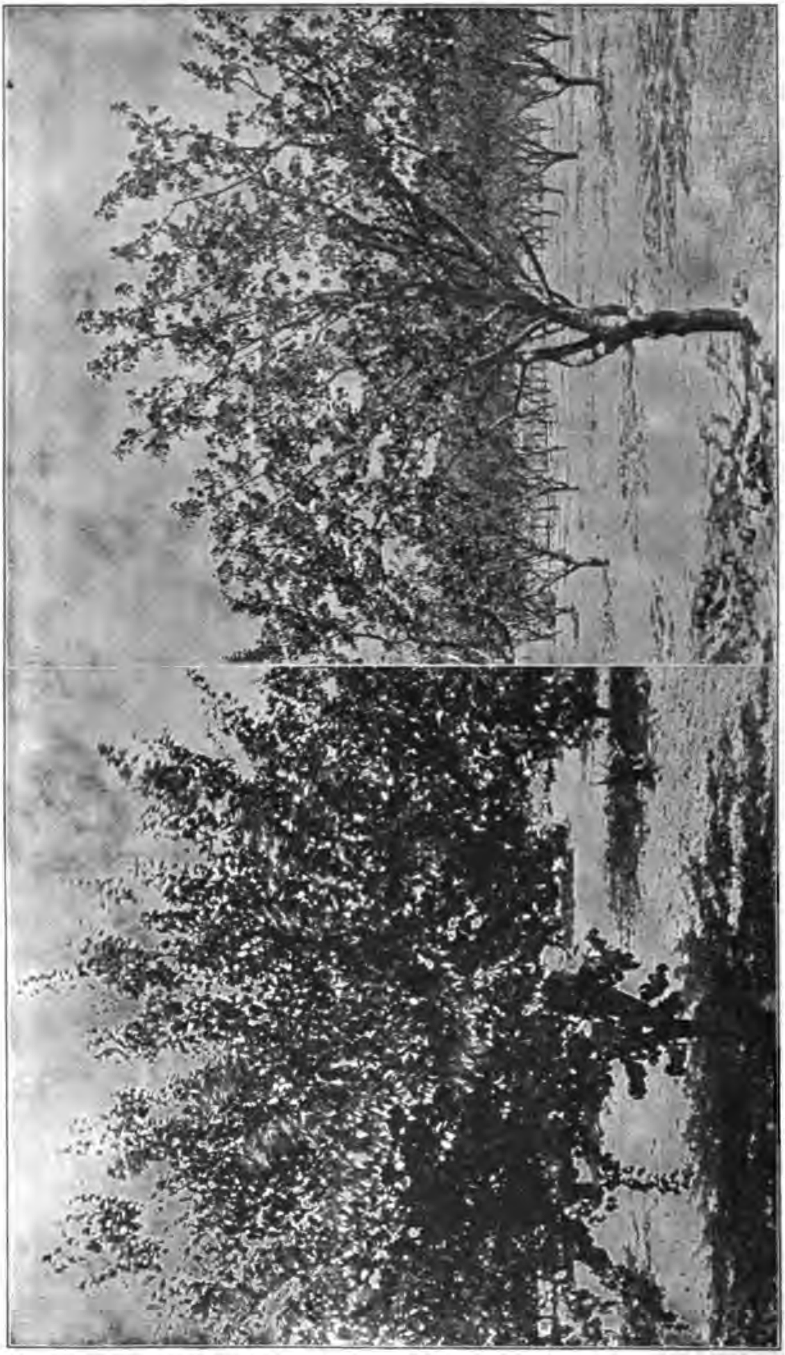
[1] Rep. Calif. Expt. Sta. for 1897-98, p. 65.



Cultivated. Figs. 48, 49.—Apricot Trees, Creek Bench Land, at Niles, Cal. Uncultivated.

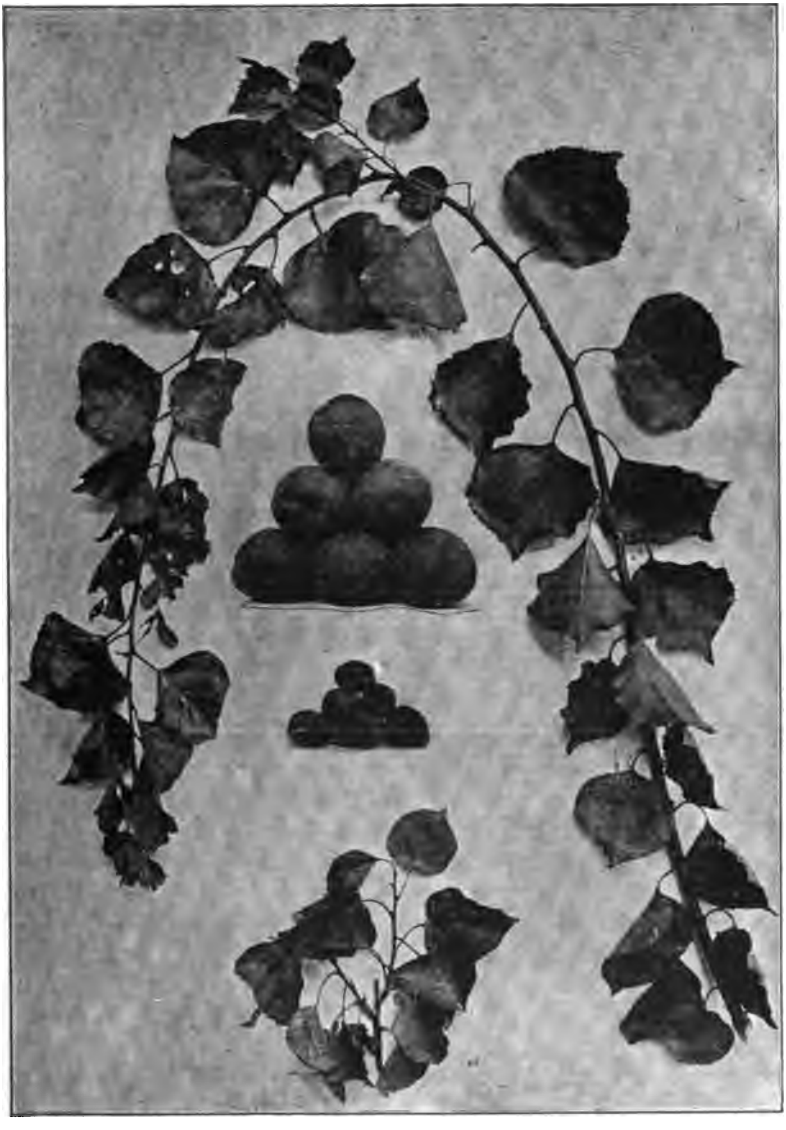


FIG. 59.—New Growth and Fruit on Trees, Cultivated and Uncultivated. Creek Bench Land at Niles, Cal.

was of good, normal size; while the trees in the uncultivated ground made barely three inches of growth, and the fruit was stunted and wholly unsaleable. It may be added that when, instructed by the season's experience, the owner of the "uncultivated" orchard cultivated deeply the following season, his trees showed as good growth and fruit as his neighbor's.

EVAPORATION THROUGH THE ROOTS AND LEAVES OF PLANTS.

Undesirable as is the evaporation from the surface of the soil, under all but exceptional conditions the evaporation from the leaves of plants is one of the essential functions of vegetable development. Not only because water serves as the vehicle of the plant-food absorbed by the roots and to be organized by and redistributed from the leaves, and the aëration occurring in the latter must of necessity result in a certain degree of evaporation; but largely because the conversion of liquid water into vapor serves to prevent an injurious rise of temperature in the leaves under the influence of hot sunshine and dry air. It is undoubtedly for the latter purpose that the greater part of the enormous amount of water required, as above stated (chap. 11) for the production of one part of dry substance, is actually used. When sufficient water to supply the required evaporation through the leaves cannot be brought up from the soil, the plant begins to wilt; or in the case of some plants with very thin and soft leaves the blade normally begins to droop during the hottest hours of the day; thus escaping excessive exposure to the sun's rays, and recovering their turgor later in the afternoon.

The amount of water actually evaporated from orchard trees has unfortunately not been directly determined, the investigations made in this respect having borne mainly upon forest trees. The Austrian Forest Experiment Station made a series of elaborate investigations on this subject in 1878, and the following data (quoted from the Report of the U. S. Dep't of Agriculture for 1889) convey some idea of the results.

It was found that the surface-areas of the leaves do not give reliable results, but that these depend very largely upon the thickness (mass) of the leaves. The dry weight of the latter was found, as in the case of field crops, to correspond most nearly so the observations made directly. It was thus found that *e. g.* birch and linden transpired during their annual period of vegetation from 600 to 700 pounds of water per pound of dry leaves; oaks 200 to 300, while the figures for ash, beech and maple were in between. On the other hand the conifers—spruce, fir and pine—ranged, under the same conditions, from 30 to 70 pounds of water only. In another year, these figures were increased for deciduous trees to from 500 to 1000, the conifers, 75 to 200 pounds. This great variability indifferent seasons, together with other elements of uncertainty, render these figures only roughly approximate ; but it will be noted that the figures for deciduous trees are in general of the same order as those given above for field crops. Assuming the evaporation for citrus trees to be approximately the same as for the European evergreen oak (*Q. cerris*) viz. 500 pounds per pound of dry matter, and taking the weighings made by Loughridge of the leaves of a 15-year-old orange tree at Riverside as a basis (40 pounds of dry leaves), the water evaporated by each such tree would be about 20,000 pounds per year, or about 1000 tons per acre of 100 trees. This is equivalent to about 9 acre-inches of rainfall, out of the 35 inches commonly given.

Since different plants evaporate very different amounts of water during a given time, according to their leaf-surface and the number and size of their stomates, the maintenance of the equilibrium between the soil-supply and the evaporation of the leaf-surface requires correspondingly varying moisture-conditions in the soil. Therefore desert plants, with their elaborate structural provisions against leaf-evaporation, will develop normally, and without wilting, under conditions which in the case of most culture plants would result in severe injury or death. Since diminution of leaf-surface will in all cases diminish evaporation, the heroic measure of cutting back the twigs and branches of shrubs and trees in seasons of severe drought is sometimes resorted to in order to save their life. In Nature this diminution of leaf-surface may be observed in many cases of desert plants, whose "fugacious" leaves are developed during the rainy season, in winter and early spring; dropping off so soon as the dry season begins, and leaving only the green surface of twigs, stems or spines to perform the functions of the leaves.

The shading of the ground by leafy vegetation will, of course, greatly diminish and sometimes suppress evaporation from the soil-surface; thus very nearly fulfilling the same conditions referred to above (chap. 7, page 111) in discussing the effect of natural vegetation in rendering tillage unnecessary; the beating of rains, and the formation of surface crusts, being alike prevented. This fact is of essential importance in contributing to the welfare of crops sown broadcast, where subsequent cultivation is impracticable.

Weeds Waste Moisture.—The injurious effects of weedy growth among culture plants are in most cases due quite as much to the appropriation of moisture that should have gone to the crop, as to the abstraction of plant-food, to which the injury is generally attributed. This is much more obvious in the arid region, where during the dry summers every pound of moisture counts, than where summer rains obscure this influence. It has led orchardists in California almost to an excess of clean culture, resulting in the burning-out of the humus from the bare surface-soil during the long, hot summers, and an injurious compacting impossible to remedy by the most careful tillage. It thus happens that greenmanuring, the natural remedy for this evil, cannot safely be done there with summer crops, but must be accomplished with winter crops, such as can be turned under before the dry season begins. The same objection holds against the growing of summer crops between the orchard-rows.

DISTRIBUTION OF MOISTURE IN THE SOIL AS AFFECTED BY VEGETATION.

The investigations of Wollny and others have long shown quantitatively what common experience has taught the farmer, viz., that a field in crops or grass is always drier within the soil-mass penetrated by the roots than is a cultivated field bare of crops, unless perhaps when heavily crusted on the surface. The depletion of moisture caused by grass sward is the most easily observed because of the shallowness of the root-system; and this is one cause at least why grass sward does not occur naturally in the arid region, and when planted cannot be maintained without irrigation repeated at short intervals. Deeper-rooted plants of course deplete the soil at different and varying levels;

and where surface roots are few or absent it may readily happen that the surface soil is moister than the subsoil.

This was very strikingly shown by the investigations of Ototzky in the South-Russian steppes, in comparing both the moisture contents and the depth of bottom water as between forest land and the open plains. On the steppe near Chipoff, Government of Voronej, he found the ground water at from 3 to 5 meters (10-16 feet) depth; under the forest in the same region and in identical underground formations, the water level stood at 15 meters. In the Black Forest near Cherson, the water is found at about 15 feet beneath the surface; under the steppe and in cultivated ground it stood at 10 feet. At the same time the forest soil was moister in the upper two feet than the soil of the steppe, where surface evaporation (partly through shallow plant-roots, partly direct) was greater than under the shadow of the forest; under which, moreover, there were few shallow rooted plants to draw upon the moisture of the surface soil.

The great evaporation from forests is a matter demonstrated by actual measurement; hence it is not surprising that certain shallow-rooted trees should serve for the reclamation of wet ground, as has been demonstrated on the large scale, *e. g.*, in the use of the eucalyptus in the Pontine Marshes of Italy, and of the maritime pine in the Landes of western France. Thus the sanitation of swampy districts through tree-planting has become one of the established measures in their settlement. But this refers only to the evaporation from the trees themselves; for in the shade of the forest, a free water-surface is found to evaporate on the average only one-third as much as in open ground. Of course there must be a correspondingly great diffence in the amounts of evaporation from the soil-surfaces in the respective areas.

The great draft made by the *Eucalyptus globulus* upon soil-moisture has been also abundantly shown in California, where on account of its rapid growth this tree has been largely used for windbreaks. It was found that the trees deplete the fields of moisture for from twenty to thirty feet on either side, so as to materially reduce crops within that limit. For this reason the pine and cypress has of late found greater acceptance for this purpose.

Mulching.—Covering the soil with straw or similar loose materials to prevent waste of moisture is a common garden practice everywhere, although not usually applicable on the large scale. It may readily however, be carried to excess, in preventing not only evaporation but also the warming of the soil which is so needful to the thrifty growth of plants. It must not therefore be done too early in the season; and after cold rains it sometimes becomes necessary to remove the mulch in order to allow the ground to become properly warmed. Mulching in early spring is often used to retard blooming of trees where spring frosts are feared.

In the arid region, sanding of the surface is sometimes resorted to for the prevention of the evaporation which brings alkali salts to the surface. But the necessity of repeating this dressing annually unless cultivation can be omitted, restricts the use of this expedient to narrow limits.

The sanding of the surface of cranberry plantations in swamps or bogs in the northern parts of the humid region doubtless owes its efficacy largely, if not chiefly, to the retention of moisture, while at the same time it prevents the consolidation of the surface, so as to render tillage unnecessary.

CHAPTER XIV.

ABSORPTION BY SOILS OF SOLIDS FROM SOLUTIONS. ABSORPTION OF GASES. AIR OF THE SOILS.

ABSORPTION OF SOLIDS FROM THEIR SOLUTIONS.

JUST as solids have the power of condensing gases upon their surfaces, to an extent proportional to that surface, and therefore to the state of fine division: so fine powders have the power of withdrawing from solutions solids held in solution, to an extent varying with the nature of the substance dissolved, and the absorbing solid. The most commonly-known manifestation of this principle is that sea-water filtering through the sands of the shore, will at a certain distance become sensibly less brackish, and finally so nearly fresh as to be capable of domestic use.[1] The extent to which this occurs is in a measure proportional to the fineness of the sand, and to the amount of clay present in it. This is a clearly physical effect, independent of any chemical action whatever; for it occurs equally with quartz sand, charcoal, glass, limestone, or other rock powders having no chemical effect upon the substance dissolved or upon the liquid dissolving it. Very large amounts of water are often required to remove all the soluble matter thus "adsorbed."

Decolorizing Action.—One of the commonest applications of this principle is the decolorization of colored solutions by means of finely pulverized charcoal. This property of charcoal, as is well known, is extensively utilized in the arts, and particularly in the refining of sugar; the charcoal used in this case being preferably bone charcoal ("bone black"), which on account of its state of extreme fineness, and separation by the earthy particles with which it is associated, is more effective than any other form. It is rendered still more effective, how-

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[1] In many cases this decrease of salinity is probably due to a slow influx of fresh water from landward; but very often it cannot be thus explained.

ever, by the extraction of these earthy particles (calcic carbonate and phosphate) by means of acid; for by removal of the earthy particles, the surface of the charcoal is greatly increased, and its decolorizing as well as its absorbing power increases accordingly.

While in one and the same substance the decolorizing effect is more or less directly proportional to the fineness of the particles, corresponding to increased surface, it is nevertheless true that in this case, as in that of the absorption of gases, there are specific differences between different powders; so that for example no other substance can replace charcoal in the decolorizing effect which it produces upon colored solutions. It must not, however, be supposed that there is any special reason why *coloring* matters, as such, should be taken up by preference. Coloring matters are of all kinds of chemical composition, and have in common only the fact that a relatively small amount produces a very strong coloring effect; hence their name, and hence also the apparently extraordinarily strong effect produced upon them by charcoal.

This effect is not, however, by any means greater than it is in the case of many other compounds which are colorless.

Complex Action of Soils.—The powdery ingredients of soils, of course, share this power with all other powders. In the case of soils, however, the action is almost always much more complex than in that of charcoal, because solutions that are passed through the soil are apt to act chemically upon one or the other of its ingredients, usually resulting in a partial exchange of ingredients between the soil and the solution; one or more of the constituents of the solution being retained by the soil, while one or more of the (basic) soil constituents pass into the solution, in combination with its acidic ingredients.

Thus when a very dilute (½ or 1%) solution of potassic chlorid is filtered through almost any soil, the first portions passing through will be practically free from potash, but will contain the chlorids of calcium and magnesium. But as more of the solution is passed through, potash passes also ultimately without absorption. In addition to the zeolitic and clay portions of the soil, the humus is very effective in absorbing

mineral ingredients from solution, and retaining them in such manner as to be readily available to plant growth. (See chap. 8, p. 124.)

In view of the almost invariable conjunction of physical and chemical effects, it may be fairly said that no solution, at least of mineral salts, can pass through the soil without being changed in its concentration and chemical composition. It is sometimes difficult to decide to which of the two classes of effects the several changes may be due.

Purifying Action of Soils.—The disinfecting action of dry soil, absorbing offensive gases from manure piles and from earth closets, has already been alluded to. Similarly it is a matter of common experience that the colored and otherwise offensive drainage from manure piles, tanneries, dyeworks, etc., is not only deodorized but also decolorized when passed through a sufficiently thick layer of clay soil. The filtration through fine sand by which the drinking waters of cities are so commonly purified before delivery to the consumer are familiar examples of the same effects.

Equally familiar, however, is the fact that this power of decolorization and retention of offensive compounds is limited; that after a while the filtering earth or sand becomes saturated, and afterwards the water or drainage will pass through without any sensible purification.

It is therefore clear that this purifying effect of earth cannot be relied upon for the permanent protection of wells from the surface-drainage from barnyard or house refuse. Even if fissures or layers of sand or gravel should not intervene so as to permit of the direct communication of surface-drainage with wells, it is certain that in the course of a few years at most, the intervening earth will become so far saturated with the noxious ingredients that the latter will pass through unhindered, and may contaminate to a considerable extent the domestic supply of drinking water.

Waste of Fertilizers.—The same, of course, holds true in regard to manure-water, or soluble fertilizers of any kind used on the soil of a field. The soil will retain them to a certain extent; but beyond that limit any surplus added will be quickly washed through into the country drainage by the rains. Moreover, a soil once so saturated will yield to rain-water filtering through it, notable amounts of all the ingredients absorbed in it; and, at least so far as the physically condensed soluble ingredients are concerned, long-continued leaching with pure water will inevitably result in the withdrawal of additional amounts of absorbed ingredients, apparently dividing themselves up *pro rata* between the water and the soil.

It is obviously of the utmost importance to the farmer to know to what extent the soil will retain manurial ingredients against the influence of leaching rains; for unless this is taken into consideration, it may readily happen that the fertilizer supplied before a rainy season will be washed through beyond the reach of plant-roots, and so practically become a dead loss.

Absorptive Power Varies.—So far as the mere physical absorption is concerned, it will readily be understood that a coarse sandy soil exercises less retentive influence upon dissolved substances than clay or humous soils. In the humid region, where sand is substantially nothing but granular silica (see above, chap. 6, page 86), the same may be measurably true as regards the chemical absorption also. In the arid region, on the contrary, a great many sandy or silt soils, very poor in clay, exert fully as much chemical absorption as clay soils, and are no more liable to the washing-out of soluble fertilizers introduced than are the latter. For the chemical absorption lies chiefly in the zeolitic portion of the soil (see above chap. 3, p. 37, which in the humid region accumulates in the clay, while in the arid it remains encrusting the sand and silt grains.

Generalities regarding Chemical Absorption and Exchange.—In regard to the leaching-out and absorption or retention of substances important to agriculture, the following general statement may be made:

The substances most likely to be leached out of soils are, of bases: soda, magnesia and lime; of acidic constituents: chlorine, sulfuric acid and nitric acid. Lime sometimes passes off with either of the above acidic ingredients, and also in the form of carbonate.

Substances rather tenaciously retained in soils are: potash and ammonia among the bases, and phosphoric acid among the acids.

Thus (as stated above) when a weak (one or two per cent) solution of potassic chlorid or sulfate is poured upon a column of good soil several inches thick, it will be found that the first portions passing through are free from potash, but contain the chlorids or sulfates of magnesium and calcium. If potassic nitrate be used, lime and magnesia will pass off as nitrates; while in the case of potassic phosphate, both ingredients will be retained. A solution of gypsum (calcic sulfate) will usually cause the passing-off of some of the magnesia, soda and potash contained in the soil, in the form of sulfates; but the amount of potash thus dissolved soon diminishes to a mere trace. Solutions of potassic or ammonic phosphates will be absorbed and retained by the soil to a very considerable extent, before the soil becomes saturated.

While it is true that the degree to which the soil retains the several ingredients may serve in a very general way to indicate their richness or poverty in the same, the attempt to make such experiments serve to determine the agricultural needs of soils has met with but little practical acceptance.

Drain Waters.—The table on p. 22, chapter 2, illustrates forcibly the working of the above principles, which are verified by the composition of drain-waters. In all, the chief nutritive ingredients of plants, except nitrogen, are present in traces only; chlorids, nitrates and sulfates of sodium and magnesium form the bulk of the permanently soluble matter, with usually a considerable proportion of calcic (and magnesic) carbonate, depending upon the amount of the earth-carbonates present in the soil, as well as upon that of oxidizable organic matter from which carbonic acid can be formed. That calcic carbonate filters readily through the soil has already been somewhat elaborately discussed (see chap. 3, p. 41); one of the results being that the surface soil is sometimes almost completely depleted of this important substance, while it accumulates at a greater or less depth in the subsoil, or in underdrains, as the case may be.

Of the ingredients appearing in the above list, the one of greatest agricultural importance is nitric acid, since chlorine and sulfuric acid, as well as soda, are required only in very small quantities by most culture plants; so that they rarely need to be supplied in fertilizers. Nitric acid, however, is not only one of the most important fertilizers, but also the most expensive; hence the passing-off of nitrates in drainage-water is of such serious concern to the farmer, that the causes of its occurrence, and the means of preventing such loss, should be fully understood. This subject will, however, be more fully considered farther on.

The above Distinctions not Absolute.—It should, however, be also understood that while the above statements hold good in a general way, yet the line drawn is by no means an absolute one. For just as in the case of physical adsorption the long passing-through of distilled water will gradually abstract the substances condensed on the surface of the soil-grains, so an overwhelming amount of a solution of any one kind will have a tendency to substitute its own ingredients for those already present in the soil, removing the latter to a greater or less extent, even in the case of potash and phosphoric acid.

As an example in point, may be cited the case of the natural minerals Analcite and Leucite, which Lemberg was able to reciprocally transform from their natural condition of soda- and potash-alumina silicates merely by alternate treatment with solutions of potassium and sodium chlorids respectively. (See chap. 3, p. 37). The same is true in the case of the zeolitic matter of the soil. There is nevertheless a distinct preference in the direction of the retention of potash as against soda; so that in the case of alkali soils, a large excess of potash is found to be present in the zeolitic form, notwithstanding the presence of sometimes very large amounts of the chlorid, sulfate and carbonate of soda. This preferable retention of potash is, of course, of material advantage in the case of the use of soluble potash-fertilizers, as well as in preventing the waste of the potash of the soil itself.

ABSORPTION, OR CONDENSATION, OF GASES BY SOILS.

Like all bodies in a state of fine division, soils are capable of absorbing a not inconsiderable amount of various gases. It may be said that in general, other things being equal, the amount thus condensed on the surface of the soil-grains is more or less directly proportional to the facility with which the gas is condensed by either pressure or cooling. Hence the very large amount of water-gas or vapor which may be absorbed by soils, as shown in a preceding chapter. But excepting perhaps the case of ammonia, moist soils are less absorbent of gases than dry ones.

Oxygen and nitrogen, the main constituents of the atmosphere, being difficultly condensable by either pressure or cold, are absorbed by soils only to a relatively small, yet by no means unimportant extent. The condensation of oxygen within the soil-mass is doubtless of considerable importance in the processes of oxidation, as is shown by its partial replacement by carbonic gas in the free air of the soil (see chap. 2, p. 17). The intensifying of oxidizing action caused by surface condensation is well illustrated in the case of finely divided platinum, in which hydrogen is brought to rapid combustion when mixed with oxygen; as well as by the effect of bedding tainted meat in charcoal powder, when all odors of decay disappear, both by absorption and oxidation, ammonia and carbonic gas alone ultimately escaping through the powder.

Carbonic dioxid and ammonia gases, both normal constituents of the atmosphere, and of high importance to plant nutrition, are more readily condensable than either oxygen or nitrogen, and consequently may be taken up by the soil in larger relative proportions. Especially is this the case with ammonia gas, which is not only readily condensed by pressure, but is also extremely soluble in water; so much so that it rushes into a tube filled with this gas almost as quickly as though it were a vacuum. Water will absorb at the ordinary temperature, under normal pressure, about 700 times its volume of ammonia gas; but inasmuch as the proportion of the latter in the atmosphere amounts to only a few millionths, the actual amount taken up can only (as in the case of all gases) be proportional to its proportion (or "partial pressure") multiplied into its coefficient of absorption. Consequently, water exposed to the ordinary air can absorb at best only a small fraction of a per cent of ammonia. Its presence in soils can be readily demonstrated by passing through the warmed soil a current of purified air, which is made to bubble through Nessler's reagent (potassio-mercuric iodid) solution.

Absorption of gases by dry soils.—Perfectly dry soils are powerful absorbers of ammonia, and their absorption of this gas, as well as of carbonic gas, can readily be shown by the arrangement shown on the page opposite.

The two tubes shown to the left are filled with carbonic gas, those to the right with ammonia gas. After being immersed in a mercurial trough, there are introduced into each tube through the mercury small cylinders (conveniently one cubic centimeter in volume) consisting respectively of a very sandy soil or loose hardpan, a gray plastic clay, a gray clay soil or adobe, a very black "adobe" clay, and a highly ferruginous and humous soil (from Hawaii), which gives the highest absorption of all; next brown peat, and pine charcoal. The latter, and the ferruginous soil, were also exposed for the absorption of carbonic gas. All the absorbing cylinders are first heated for an hour to 110°C. (218°F) for the purpose of expelling from them moisture, air, and other absorbed gases. They are then quickly introduced into the tubes through the mercury and allowed to absorb the gases enclosed until the mercury columns cease to show any farther rise; in which condition they are shown in the figure.

It will be seen that this absorption is a different one, not only for each of the different substances used, but is also differently proportioned for the two gases. For it will be noted that while the clay soil has absorbed a very much larger amount of ammonia than the charcoal, and the sandy soil has remained far behind both: yet the charcoal has absorbed a considerably larger *proportion* of carbonic gas than either the clay or the sandy soil, proving that charcoal has a strong *specific* absorptive power for carbonic gas, independently of the relative size of clay and charcoal particles respectively. The sandy soil shows, by its low absorption even of ammonia gas, the coarseness of its particles and the scarcity of clay in its composition. The highest absorption of all is shown by the ferruginous soil from Hawaii, containing nearly 40 % of ferric oxid together with 3 1-3% of humus. The moisture-absorption of this soil at the ordinary temperature is 19.7 per cent. The difference in the absorbing power of the (non-humous) gray clay and gray adobe soil indicates the strong influence of humus upon the absorption; which is still farther emphasized by the difference between the gray and black adobe, the latter containing 1.2% of humus. As to the peat, since its weight was only .5 grams against an average of 2 grams for the soils employed, its absorptive power *by weight* doubtless exceeds all other substances.

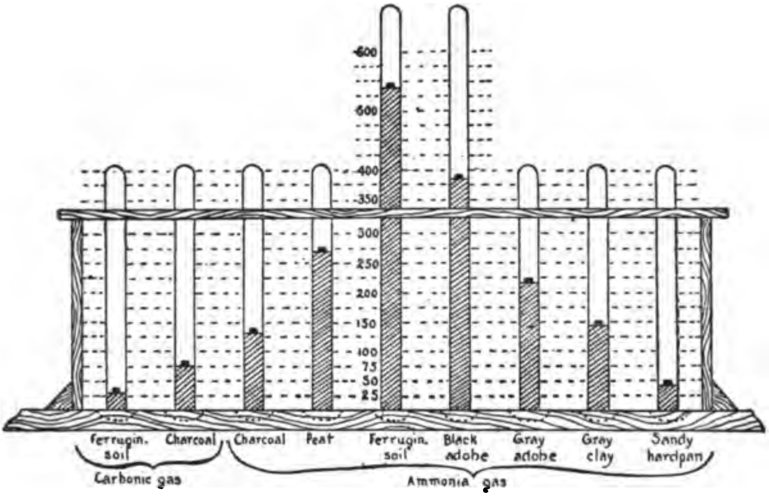

FIG. 51.—Absorption of Carbonic and Ammonia Gases by different Soils.

While the experiment shown in the figure serves as a convenient and striking demonstration for lecture purposes, it is of course not adapted to a direct comparison of the absorbing powers of the several substances, because of different heights of the mercurial columns counteracting the atmospheric pressure. For direct comparative measurement the tubes must be sunk in mercury so as to equalize the levels inside and outside, since the corrected volumes obtained by calculation would not serve the purpose.

According to special measurements made under normal atmospheric pressure, the writer found that a black clay soil (" adobe ") absorbed (at 60°F) over two hundred times its bulk of ammonia gas, while under the pressure of one-fifth of an atmosphere (as shown in the photograph) the absorption was one hundred and twenty-three times its bulk. This energetic absorption of ammonia and related gases explains the marked disinfecting effects which a covering of dry earth exerts in the case of cemeteries, manure piles, and earth closets. But the difference between the sandy soil and the clay soil in the amount of absorption admonishes us that in all these cases, to secure disinfection the earth to be used should contain as much clay as possible, and should not be mere sand, as is sometimes the case. It also shows that the addition of charcoal to such materials does not increase their efficacy, as has been supposed, but that an equal bulk of clay would be more efficient.

Of course, so soon as the absorbing cylinders used for this experiment are exposed to the atmosphere, the principle above stated in regard to "partial pressure" asserts itself. The absorbed gases quickly begin to be given off, and in some hours the equilibrium with the ordinary conditions of the atmosphere is reëstablished. That the strong absorptive power of soils for ammonia is to some extent effective in maintaining the supply of this substance by absorption from the atmosphere, cannot be doubted.

Boussingault, and later Stenhouse, determined the absorptive power of wood charcoal for ammonia to be 90 and 98 volumes respectively.

THE COMPOSITION OF GASES ABSORBED FROM THE ATMOSPHERE BY VARIOUS SOLIDS.

In 1864 and 1865 Reichardt and Blumtritt[1] investigated elaborately the composition of gases driven off by heat from various powders, including soils, exposed to the atmosphere. All the substances examined were therefore "air-dry," therefore to a certain extent moist; and the presence of this aqueous vapor of course modifies in a measure the results that would have been obtained had the materials used been exposed to dry air only. They found that, as had already been stated by previous observers, the presence of capillary water *diminishes* materially the absorption of gases, especially of those not as easily absorbed by water as are carbonic gas and ammonia. Contrary to what might have been expected from the more ready condensation of oxygen by pressure or cold, in nearly all cases nitrogen is absorbed to a greater extent than oxygen, and sometimes exclusively so; so that in some cases the latter was found to be present only in traces, as will be perceived from the subjoined table:

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[1] Journal für praktische Chemie, Vol. 98, p. 167.

COMPOSITION OF GASES ABSORBED FROM THE ATMOSPHERE BY VARIOUS POWDERS.

Substance.	100 Grms gave cc. Gas.	100 Vol's gave Vol's. Gas.	100 vol's gas contained			
			Nitogen.	Oxygen.	Carbonic Dioxid.	Carbon Monoxid.
Charcoal, coniferous, air-dry	16.21	....	100.00	0.0	0.0	0.0
" moistened and air-dried	140.11	59.0	85.60	2.12	9.15	3.13
" Lombardy Poplar	466.95	195.4	83.60	0.0	16.50	0.0
Peat	162.58	....	44.44	4.60	50.96	0.0
Garden Earth, moist	13.70	19.9	64.34	2.85	24.06	8.75
" " air-dried	30.28	53.6	64.70	2.04	33.26	0.0
River Silt, air-dried	40.53	48.07	67.69	0.0	18.61	13.70
" " slightly moistened	24.12	29.2	67.34	0.0	30.56	2.10
" " air-dried	26.52	30.05	67.40	9.09	16.07	7.44
Clay, long exposed	25.58	39.05	70.17	4.71	25.12	......
" slightly moistened	28.62	35.08	59.59	6.39	34.02	......
Ferric Hydrate, commercial	251.59	275.0	33.26	1.43	65.31	0.00
" " freshly precipitated, air-dried	375.54	308.6	26.29	3.85	69.86	0.00
" Oxid, ignited	39.4	52.4	82.87	13.41	3.72	0.00
Aluminic Hydrate, air-dried	69.02	82.0	40.60	0.00	59.40	......
" " dried at 100°C	10.83	13.6	83.09	16.91	0.00	......
Prepared Chalk, 1864–65	43.48	52.4	100.00	0.00	0.00	. ....
" " 1865	38..98	48.0	74.49	15.49	10.02	......
Calcic Carbonate, precipitated, 1864–65	65.09	....	80.81	19.19	0.00	......
" " " 1865–66	51.53	52.0	77.37	15.09	7.54	......
Magnesic Carbonate	729.21	124.9	63.92	6.72	29.36	......
Gypsum, finely powdered	17.26	....	80.95	19.05	0.00	......

Discussion of the Table.—It will be observed that in this table, the largest amount of total gas given off by equal weights of any one substance was in the case of carbonate of magnesia; but it is quite probable that in part, at least, this large amount of gas was due to the evolution of carbonic gas from the easily decomposable carbonate; the more as the analysis of the gases shows over 29% of carbonic gas. But the highest absorption by equal *volumes* of any substance is shown by the ferric hydrate; next to this by the light poplar charcoal, and next by the carbonate of magnesia. The high absorptive power here shown by the ferric hydrate is of great interest in connection with the facts already stated regarding the absorption of moisture and ammonia by ferruginous soils (see page 274, this chapter); and the fact that the larger proportion of the gas—as much as 70% in one case—consisted of carbonic gas, is particularly interesting in the same connection. Both in the amount of gas contained, and in the proportion of carbonic gas therein, the ferric hydrate exceeds even peat, the representative of humus in soils. It will, however, be noted that in the garden soil, also, the proportion of carbonic gas is very large, while that of oxygen is very low. It is curious to note that in very few cases the proportion of oxygen to nitrogen is the same as in the atmosphere; in most cases the nitrogen predominates considerably beyond its normal proportion, and in two cases, that of charcoal and of calcic carbonate (whiting), the gas was found to consist of pure nitrogen.

We are forced to conclude that the substances here enumerated, as a rule, condense oxygen in smaller proportions than they do nitrogen, or carbonic gas. As regards the carbon monoxid mentioned in the table, it is doubtful that it was contained as such in the substance originally examined; it may readily have been formed under the influence of the heat required in expelling the gases from the substances containing organic matter. Among the important results shown in the table, is the comparative determination of the gases in moist, and in dry garden earth, showing that in the moist earth the amount of gas absorbed ranged from less than one-half down to almost one-fourth that absorbed by the dry. The importance of these differences in the case of the fallow can readily be appreciated.

The changes in the absorptive power brought about by wetting and drying, as shown in the above table, are very insignificant. In the case of the charcoal, soil and silt the diminution may fairly be assumed to be caused by the deposition of soluble salts on the surface, partly clogging the pores. In the case of the clay as well as in that of the river silt, the inevitable content of organic matter in process of decomposition has doubtless influenced the result, as is suggested by the increase of carbonic gas. That prepared chalk should in one case contain exclusively nitrogen gas, in the other case mixed gases, seems to indicate a difference in the air to which it is exposed, or in the water employed in its preparation; the latter case agreeing substantially with the results obtained from the precipitated carbonate. In both (as well as in the carbonates of barium and strontium), the absorption of carbonic gas is very small, or *nil.*

It thus appears that for the condensation of carbonic dioxid gas, ferric and aluminic hydrates are prepotent among mineral substances; while clays, river silts and soils may always be expected to contain relatively large proportions of this gas in absorption.

THE AIR OF SOILS.

The Empty Space in Soils.—In dry soils the empty space, usually amounting to from 35 to 50 per cent of its volume, is filled with air;[1] in moist or wet soils the space unoccupied by water is similarly filled. Hence when soils are in their best condition for the support of vegetation (chap. 11, p. 202), about one half of their interstices is filled with water, the other half with air. Actual measurements of the amount of air contained in well-cultivated garden soil have been shown by Boussingault and Levy to range between 10,000 and 12,000 cubic feet per acre, substantially agreeing, therefore, with the above statement. In uncultivated forest soil, on the contrary, they found only from somewhat less than 4000 to 6000 cubic feet of air per acre. Extended observations since carried out by Wollny, Ebermayer, and others have in general confirmed the earlier observations, while adding greatly to their significance in respect to their relations to plant growth, and to the process of humification and soil-formation.

As a matter of course, when water evaporates from the soil in drying, its place is taken by air so far as it is not filled by capillary water drawn from below.

Functions of Air in Soils.—That roots require for the performance of their vegetative functions the presence of oxygen, has already been discussed; but there can be no question that the higher productiveness of well-cultivated soils is largely due to the greater and readier access of air to the roots. Apart from this direct function, however, the presence of oxygen in the soil serves other important purposes, and among these doubtless the most dominant is the promotion of the oxidation of the organic matter of the soil through the agency of micro-organisms; and more particularly that of nitrification, which chiefly governs the supply of nitrogen to non-leguminous plants. In the case of leguminous plants, the presence of air as a furnisher of nitrogen as well as oxygen is absolutely essential.

The injurious effects of insufficient aëration of the soil have been repeatedly referred to already (pp. 45, 76). In water-logged soils reductive fermentations are soon set up, and the

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[1] The normal composition of atmospheric air is given on p. 16, chap. 2.

nitrates of the soils are reduced partly with the evolution of nitrogen gas, partly to ammonia; while their oxygen is consumed to supply the demands of the roots. Ferric oxid is reduced to ferrous carbonate, sulfates to sulfids; thus deranging the whole process of plant-nutrition and absorption of plant-food. If continued for any length of time these conditions end in the death of the plant. Too much importance cannot therefore be attached to the proper aëration of the soil and subsoil.

Excessive Aëration; Compacting the Soil.—On the other hand, excessive aëration of the soil may be injurious in causing a serious waste of moisture; especially in arid climates, where the hot, dry winds may readily destroy the germinating power of the swollen seed when the seed-bed is too loose and open, and later may injure or destroy the feeding roots. The abundant growth of grain often seen in the tracks of a wagon carrying the centrifugal sower, when the stand in the general surface is very scanty, is usually due to the consolidation of the seed-bed, and suggests at once the well-known efficacy of light rolling to insure quicker germination and a better stand. Similarly, the rolling of grain fields in spring is often the saving clause for a crop in dry years. But such needful consolidation must not, of course, be carried to the extent of creating a surface crust which would subsequently serve to waste the subsoil moisture. Hence, the soil-surface should be rather dry when rolling is resorted to.

The pressing of the earth around transplanted plants, similarly, is a needful precaution, not only with respect to the drying-out of the soil, but also to insure close contact between the roots and the soil.

The Composition of the Free Air of the Soil usually differs from the air above, in that besides being saturated with moisture, its nitrogen-content is slightly increased (by one-half to over one per cent); the oxygen-content on the other hand, is diminished, being in part (sometimes nearly to the extent of one-half of its volume) replaced by carbonic gas, derived partly from its secretion by the roots, partly from the oxidation of organic substances. It naturally follows that the richer the soil in the latter, the more carbonic gas will be formed under favoring conditions; so that in freshly-manured land the amount of oxygen transformed into carbonic gas will be greatest, while in the surface-soil of ordinary fields, carbonic gas rarely reaches to as much as one per cent. In all cases, however, the content of carbonic gas in the air of the soil is materially higher than that of the air above it, and thus serves to intensify greatly the solvent and disintegrating effect of the soil water upon the soil materials (see chap. 2, p. 17). The soil-mass itself, however, retains carbonic dioxid with considerable tenacity, so that it is not possible to wash it out completely by filtering water through it. When water containing carbonic gas in solution is filtered through the soil, the gas is sometimes completely absorbed, the water passing off free from gas.

The presence of free carbonic gas in soils is readily demonstrated by passing through the warmed soil a current of air, which is then made to bubble through lime water; a clouding of the latter, and the ultimate formation of a precipitate of calcic carbonate, proves the presence of the gas, and may also serve to measure its amount.

From the fact that the free air in normal soils may contain as much as one-fortieth of its bulk of carbonic gas, besides what may be contained in the condensed form, we may conclude that this gas is formed within them with considerable rapidity; for otherwise, in view of the free communication and diffusion with the outer air, such large amounts could not be maintained in the surface-soil. Doubtless a considerable proportion of the carbonic gas normally contained in the atmosphere is thus supplied from within the soil itself.

Relation of Carbonic Gas to Bacterial and Fungous Activity. —It has been fully demonstrated by the researches of Koch, Miquel, Adametz, Fuelles, Wollny and others, that the formation of carbonic gas in the soil is not a purely chemical oxidation process, but is essentially dependent upon the presence and life-activity of numerous kinds of organisms, bacterial as well as fungous. The crucial proof of this fact is that the presence of any antiseptic diminishes, and if exceeding certain proportions completely suppresses, the formation of carbonic gas; while on the other hand all conditions known to be favorable to the life of such organisms, viz., the proper conditions of temperature and moisture (varying with different kinds), increase the formation of the gas. Such formation is of course, however, conditioned upon the presence of oxygen. In the case of most bacteria, there is a certain limit beyond which the presence of their own product exerts an injurious or repressive effect upon their activity; so that if the gas accumulates beyond that limit, the rate of its formation decreases despite of otherwise favorable conditions.

It follows that the best life-conditions of these organisms (even when anerobic) cannot be fulfilled below a certain limited depth in the soil; and all observations show that their number decreases very rapidly with increasing depth (see chap. 9, p. 142), varying with the perviousness of the soil, but rarely exceeding four or five feet in the humid regions; though doubtless found at greater depths in the arid climates. It is also obvious that the use of any antiseptic or poisonous materials on the field or in the manure pile will tend to disturb and restrain the useful activity of these organisms.

Putrefactive Processes.—Carbonic gas is formed also, but to a much more limited extent, in *putrefactive processes,* occurring in the absence, or with only limited access, of air or oxygen. These processes likewise are conditioned upon the presence or activity of (largely anerobic) bacteria; but they should not occur in normally constituted, and especially in tilled soils, being as a rule inimical to the growth of cultivated plants (see chap. 9, p. 145).

CHAPTER XV.

THE COLORS OF SOILS.

THE natural coloration of soils forms a prominent part of the characters upon which farmers are wont to base their judgment of land quality; hence the origin and value of soil-colors deserve consideration.

Black Soils.—From the oldest times down to the present a "rich, black soil" has commanded attention and approval. The black and brown-black colors being almost invariably due to the presence of much humus (very rarely to an admixture of carbon (graphite), of magnetic oxid of iron, or sesquioxid of manganese), it is obvious that the farmers' judgment coincides with a high estimate of the agricultural value of humus. A discussion of this point will be found in another place; but the popular judgment is based quite as much upon the experience had in the advantages that usually accompany the presence of humus. It largely characterizes low grounds, and therefore alluvial lands, whose richness is due to far more general causes. But the *shade* of the blackness seen in the soil deserves and usually receives close consideration. If tending toward brown, acid humus or "sour" land is indicated; unless indeed the surface soil should be bodily derived from decayed wood, as in the primeval forests. Forest soils in general are usually dark-tinted for some inches near the surface, owing to the presence of leaf mold, and mostly have an acid reaction.

But the black tint is equally welcome to the land-seeker when seen outside of alluvial and forest areas. Belts of "black lands" appear on hillsides and plateaus; and these lands, though clearly not alluvial, are also found to be preëminently productive; witness the upland prairies of the western and southern United States. These black soils are always characterized by the presence of a full supply of lime in the form of carbonate, under the influence of which the most deeply black humus is formed. In other words, the jet black tint is indicative of calcareous lands; and these, as will be more fully shown below, are almost always highly productive.

From both points of view, then, the favorable judgment passed upon black soils by practical men is justified.

But it is not necessarily true that soils showing no obvious black tint are poor in humus; for in strongly ferruginous or "red" soils its tint is frequently wholly obscured, though when still visible it gives rise to the laudatory name of "mahogany land," which every farmer considers a prize.

Of course then it would be wholly incorrect to judge of the agricultural value of land from its humus-content alone; for its color may be entirely imperceptible and yet its amount and nitrogen content be fully adequate to the requirements of thrifty vegetation. Gray and even whitish soils very frequently fall within this category in the arid region.

The black tint is also favorable to the absorption of the sun's heat, and is therefore conducive to earlier maturity than is to be looked for in light-tinted lands similarly located.

Wollny (Forsch. Agr. Phys. Vol. 12, 1889, p. 385), discusses the influence of color on soils in relation to moisture and content of carbonic acid. The results show in general simply the effects due to increase of temperature when the soils are either darker-colored throughout, or made so superficially.

"Red" Soils.—Next to a black soil, a "red" one will usually command the instinctive approval of farmers. The cause of this preference is not as obvious as in the case of the black tints; but the general consensus of opinion requires an examination of its claims. It is of course easy enough to adduce examples of very poor "red" soils, derived from ferruginous sandstones that supply little else than quartz and ferric hydrate; the Cotton States supply cogent examples in point, as do also the lower Foothills of the Sierra Nevada of California. It is not, therefore, the iron rust or ferric hydrate that renders the land productive; but its presence is a sign of some favorable conditions. First among these is, that ferric hydrate cannot continue to exist in badly drained soils; a "red" soil is therefore a well-drained one, and this is probably one of the chief causes of the popular preference. The "white land" sometimes seem in tracts otherwise colored with iron, is distinctly inferior in production to the red lands; and examination

will generally show that from some cause, such white lands have been subjected to the watery maceration which proves so injurious (see chap. 3, p. 46, chap. 12, p. 231).

That finely-diffused ferric hydrate has a very high power of absorbing moisture as well as other gases of the atmosphere, has been shown in the preceding chapter; it stands in this respect next to humus itself, and hence highly ferruginous soils need not contain as much humus as "white" soils from this point of view. Like humus, also, it renders heavy clay soils more easily tillable.

Origin of Red Tints.—Where crystalline rocks prevail, the red tint usually indicates the derivation from the weathering of hornblende; implying also, outside of the tropics, the presence of sufficient lime in the land. Such lands are naturally preferred to those of lighter tints derived from purely feldspathic rocks (see chap. 3, p. 32), although they may be poorer in potash than the latter.

But the red tint has also its intrinsic advantages in the more ready absorption of the sun's heat by the colored than by a white surface. This is probably the chief cause of the higher quality of wines grown on red hillsides in the middle and northern vine districts of Europe, where everything that aids earlier maturity is of the greatest importance. The function of ferric oxid as a carrier of oxygen (chap. 4 p. 45) probably also aids nitrification.

"Yellow" lands owe their tint, of course, to smaller amounts of ferric hydrate, but share more or less in the advantages of the "red."

White soils, or more properly those having very light gray tints, are not usually looked upon with favor, especially in the humid region. The causes of the unfavorable judgment current among farmers in respect to white soils has already been partially explained in the discussion of the black and red tints. The light color means the scarcity or absence of both humus and ferric hydrate, and usually implies that the soil has been subject to reductive maceration through the influence of stagnant water; reducing the ferric hydrate to ferrous salts, oxidizing away the humus, and accumulating in the form of inert concretions most or all of the lime, iron and phosphoric acid of the soil mass (see chap. 3, p. 46, chap. 10, p. 184). The term "crawfishy," so commonly applied to white soils in the eastern United States, expresses well the usual condition of the white soils of that region; which are very commonly inhabited by crayfish, whose holes reach water a few feet below ground, and are surrounded on the outside by piles of white subsoil mixed with "black gravel" or concretions of bog iron ore. It is needless to say why such lands cannot command the favorable consideration of the farmer; they cannot as a rule be cultivated without previous drainage, and even after that will usually prove unthrifty, "raw," and in immediate need of fertilization by greenmanuring, and the use of phosphates.

In the arid region, lands of this character are of rare occurrence, while (as has been explained above, chap. 8, p. 135), the light gray or "white" tints are there a very common characteristic of even the very best soils. It is true that they are poor in humus and in finely diffused ferric hydrate; but their "light" texture renders the presence of humus for this purpose less needful, and as stated elsewhere (see chap. 8, p. 135), the high nitrogen-content of arid humus renders a smaller supply adequate for vegetative purposes. As to iron, its presence being more important as a sign of good drainage and aëration than directly, its absence from soils of great depth and loose texture is of no consequence; especially when the heat-absorption which it favors is not only not needed, but is usually already in undesirable excess during the hot summers.

White Alkali Spots.—In the valleys of the arid region, however, *very* white spots commonly indicate the prevalence of alkali salts, and to that extent are an unfavorable indication; especially when coupled with the occurrence of black rings or spots, which indicate the presence of black alkali or carbonate of soda (see chap. 22).

CHAPTER XVI.

CLIMATE.

Heat and Moisture are the main governing conditions of plant growth.' In a preceding chapter the relations of soils and plant growth to water have been considered; in the present one the relations of both moisture and heat to soils and plants will be discussed; and to do this intelligibly to those not making a specialty of such studies, it becomes necessary to introduce, first, a summary consideration of the subject of climate.

Climatic conditions control, and to a great extent determine, the industrial pursuits of every country; all the more so as the rapid communication and transportation by means of modern appliances now brings every part of the globe in competition with every other. The question is not now what it may be intrinsically possible to do under certain climatic and geographical conditions, but whether these things can be done with a reasonable prospect of profit and commercial success, in competition with other countries offering more or less of similar possibilities. While it is true that the cost of labor frequently enters most heavily into such problems, yet favorable or unfavorable climatic or soil-conditions may in many cases turn the scale. Thus the high price of labor and fuel on the Pacific coast of the United States would at first blush seem to render competition with Europe and the East in the production of beet sugar commercially impossible; yet exceptionally favorable climatic and soil-conditions concur to turn the scale in favor of California at least, so as to have placed that state at the head of the sugar-producing states of the Union. A general understanding of the climatic conditions which concern the United States more or less directly, is therefore needful to an appreciation of their agricultural possibilities.

Climatic Conditions.—The factors usually mentioned as constituting climate are temperature, rainfall and winds. Since the latter two factors, however, are themselves merely the result of ***heat*** conditions, it is proper to discuss from the outset the origin and mode of action of heat.

TEMPERATURE.

The temperature of stellar space outside of the atmosphere is known to be very low. The increasing cold as we ascend to greater heights, is a fact familiar to all. Langley has calculated upon the basis of observations made at the summit and foot of Mount Whitney in California, that the temperature of space lies near 200° Cent. (360° F.) below the freezing point of water; and this would be the temperature near the Earth's surface, were it not for the surrounding atmosphere. The latter absorbs but a small amount of the sun's direct heat rays (which are of ***high*** intensity), as they penetrate it to the Earth's surface. But as the earth's surface is warmed, the heat rays of *low* intensity which it emits cannot pass back through the atmosphere to the sun or to outer space; they are "trapped," as it were, by the dense air resting near the earth's surface, which is then warmed partly by the radiation from, partly by direct contact with, the soil. It is to the existence of our atmosphere, then, that the possibility of our animal and vegetable life in their present form is due; and a decrease of the trapping effect on the sun's heat rays makes itself quickly felt when ascending, either in balloons or on high mountains. Moreover, it is well known to mountain climbers that at great elevations the sun's heat is extremely intense at noon; even though the temperature may fall to the freezing point at night, owing to the failure of the thin air to prevent the radiation back into space of the heat absorbed during the day. On the high plateaus of the Andes and of Asia, therefore, very extreme climates prevail, on account of the great range of temperature between day and night.

Ascertainment and Presentation of Temperature-Conditions. —The proper understanding of the temperature conditions of any locality or region is by no means a simple matter. Shall we study the daily, monthly, or annual changes of temperature, or the means deduced from either or all of them, in order to gain a clear insight into the climatic conditions that control crop production and health conditions?

The Annual Mean Temperature not a Good Criterion.—Since one and the same figure may result equally from the averaging of two widely divergent data, and from such as are close together, it is clear that the mean *annual* temperature cannot be a proper criterion of the agricultural adaptations of a country. Thus an average temperature of 60° F. might result, equally, from the averaging of 65 and 55 degrees, or from taking the mean of 15 and 105 degrees; yet the respective cultural adaptations would be widely different.

Extremes of Temperature are Most Important.—It is, on the contrary, rather the *extremes* of temperature, more particularly of cold, but frequently also of heat, together with the total amount of heat available during the growing season, that determines such adaptation so far as temperature is concerned; for no culture plant can be successfully grown where the temperature during winter even occasionally falls for more than a few hours below the point which it can resist; and for each plant there is a certain aggregate requirement of heat to carry it from germination to fruiting. Even different varieties of one and the same plant differ materially in the latter respect, so that it is very important that in the selection of varieties to be grown, this factor should be taken into consideration. It cannot be too strongly urged that the comparison of *annual* means of temperature, so commonly made by promoters of colonization schemes, must not be taken as a guide either in the estimate of cultures in which the immigrant may desire to engage, or by those in search of a climate adapted to their health-conditions.

Seasonal and Monthly Means.—The statement of the mean temperatures of the conventional four seasons—spring, summer, autumn and winter—afford a much clearer conception of climatic adaptations; provided always that the extreme temperatures be considered at the same time. With the same understanding, the monthly means are still more instructive; but here again, it is most essential that the distribution and amount of rainfall in each be regarded at the same time, since the most desirable temperature is of no avail without the moisture required for vegetation.

In some cases, *e. g.*, that of California, it becomes necessary for practical purposes to regard the "season," and not the calendar year, as the unit or reference for crop production. There the crops depend upon what rainfall may occur from October to May, there being no summer rains of agricultural significance, and outside of irrigated lands, almost all vegetation save that of trees being in abeyance. In India, there are two distinct growing seasons (" kharif " and " rabi "), corresponding to the two " monsoon " seasons; and no matter how much rain may fall during *one,* almost total failure may occur in other tropical and arid sections of that country.

The *Daily Variations* are of interest chiefly with respect to health conditions, since most plants are more adaptable in this respect than the average man.

RAINFALL.

Distribution Most Important.—The summary statements of the annual rainfall are almost equally as deceptive as are those of annual mean temperature, since quite as much depends on the manner in which it is distributed through the year, as upon its absolute amount; and also upon the manner of its fall. Thus Central Montana has the same aggregate annual rainfall as the country surrounding the Bay of San Francisco, viz. about 24 inches; but while in the Franciscan climate this amount of rain falls during one-half of the year, and that the growing season, enabling crops to be grown without irrigation, in Montana the rainfall is distributed over the entire season, so that irrigation is absolutely essential for the successful production of crops. This so much the more as, while the winter snowfall is very light, the rains of summer are largely torrential, running off the surface in muddy floods and giving little time for absorption into the soil. Farther west, in Washington, where grain crops are largely grown without irrigation, the sowing of winter grain is impracticable because the dry summer is immediately followed by the very light snowfall of winter, which falls on dry ground. Fall-sown grain would thus simply lie dormant in the ground through the winter, with great liability to injury from stress of weather in early spring, apart from the depredations of birds and rodents. Hence grain is always sown there in spring only.

These examples may suffice to show that summary statements of either temperature or rainfall by yearly means are of little practical interest to the farmer. What he needs to know is whether or not sufficient rains to mature a full crop are likely to fall during the time that the growing temperature prevails; and what are the minima and maxima of temperature —heat and cold—that his crops will be called upon to endure.

WINDS.

The third climatic factor mentioned, the winds, though proverbial for their unreliability and inconstancy, are not only very incisive in their action, but also to a considerable extent of very definite local or regional occurrence and significance. Moreover, their occurrence, direction, temperature and moisture-condition can, in regions whose climatology has been reasonably well studied, be foretold with sufficient accuracy to be of great use to the farmer.

Heat the Cause of Winds.—As already stated, the primary cause of all winds is heat, substantially on the principle according to which draught is created in our domestic fires. The hot air rising creates an indraught from all directions, especially from that which it can most readily come; viz., from the ocean,[1] or from level lands, rather than across mountain chains. Hence the sea-breeze in the after part of the day, when the land has become heated; while the sea, requiring a much larger amount of heat to change its temperature to a similar extent, remains relatively cool. But at night the earth cools more rapidly than the sea, by radiation; hence toward evening

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[1] A striking case in point is the regular wind which in summer blows through the "Golden Gate," a gap in the Coast Range connecting the Pacific Ocean directly with the great interior valley of California, along the bays of San Francisco, San Pablo, and Suisun. The great interior valley and adjacent mountain slopes becoming intensely heated during the rainless summer, the ascending air is replaced by a steady indraught from the sea, which is bordered by a belt of cold water causing fogs along the coast. The fogs are quickly dispelled on reaching the edge of the valley near the middle of its length; whence steady breezes blow northward and southward, up the valleys of the Sacramento and San Joaquin respectively. These winds, popularly often, but erroneously, called tradewinds, are really "monsoons" similar in their origin to those of India, which, when coming from the sea cause rains, but when from the heated land itself are hot and dry; as in the case of the sirocco of Italy and North Africa, the terral of Spain and the northers of California.

the sea-breeze dies down, and toward and after sunset the land-breeze takes its place.

The principle of this local change of winds, together with the rotation of the earth, the absorption of moisture by air, and the fact that the latter becomes cooler when it expands on rising and warmer when it is compressed by descending, serves to explain all the major phenomena usually observed in connection with winds. The air of the equatorial belt, heated throughout the year, necessarily rises and creates an indraught from both north and south; but since the air thus flowing in has a lower rotary velocity than the earth's surface at the Equator, it lags behind and so gives rise to northeast and southeast winds, respectively, between the two tropics and the equatorial belt. These regular winds, from the aid they give to commerce in passing from continent to continent, are known as the *trade winds.* On the other hand, the air that has risen from the hot equatorial belt, cooling by expansion as it rises and flowing northward and southward from the Equator, on descending as it mainly does into the temperate zones, has a higher rotary velocity than the land-surface and so tends to give rise to southwest and northwest winds in the northern and southern hemispheres respectively. At sea, on coasts and in level inland regions to windward of mountain chains, such winds are often quite regular during a portion of the year.

Cyclones.—But local disturbances arising from heated land areas or mountain slopes, as well as wide atmospheric changes whose causes are not fully understood, give rise to waves of alternating high and low barometric pressure, largely converting rectilinear or slightly curved wind-motion into whirls or "cyclones" [1] ranging from a thousand to over two thousand miles in diameter. These in the case of low-pressure waves or centers, *toward* which the air flows from the *outside,* revolve in the direction contrary to the movement of the hands

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[1] This designation is popularly and incorrectly applied to the comparatively limited, but very violent and destructive rotary storms or whirlwinds which originate locally on the heated plains of the Middle West of the United States, and are almost always accompanied by violent electric phenomena. These should properly be called *tornadoes.* At sea such whirlwinds give rise to waterspouts, in deserts to sand storms.

of a clock, and commonly produce rain in their east portion. A high-pressure wave or center, *from* which the air naturally flows toward the *outside,* will usually bring about an "anti-cyclone" area with fair, and in winter cold ("blizzard") weather, the direction of the whirl being, in this case, the reverse, or in the same direction as the hands of a clock. Both cyclones and anti-cyclones move in North America from west to east, mostly entering from the Pacific Ocean off the northwest coast and traversing the continent with a slight southeast (or in the case of cold weather almost south) trend, with a velocity of twenty to thirty miles an hour; until upon reaching the region of the Great Lakes they generally turn northeastward and pass into the Atlantic Ocean from the New England and Canada coasts.—It is upon these general facts, roughly outlined here, that the weather forecasts are in the main based; taking into consideration, of course, the local or regional conditions, topography, etc., which modify the application of the general rules.

In the southern hemisphere, the air-movements substantially correspond to those observed in the northern, so far as not modified by mountain chains; as is especially the case in South America.

INFLUENCE OF TOPOGRAPHY.

Rains to Windward of Mountain Chains.—The surface features or topography of the regions traversed by the air currents or winds may materially modify both their direction and their physical condition, especially as to moisture and temperature. Mountain chains may deflect them, or, causing the air currents to rise on their slopes, and thus to cool by expansion, the moisture these bring with them from the sea may be partially, or sometimes almost wholly, deposited in the form of rain or snow; chiefly on the windward slopes. Then, continuing across the range, the air deprived of most of its moisture cannot readily yield up more; hence the scarcity of rain—"arid climate"—under the lee of mountain chains; as in the Great Basin between the Sierra Nevada and Cascade ranges on the one hand and the Rocky Mountains on the other, and also on the Great Plains under the lee of the latter. The abundant rainfall between the Mississippi river and the Atlantic coast is due to the moist winds coming from the warm waters of the Gulf of Mexico and Caribbean sea, whose access is not interfered with by any cross-ranges of mountains. But the Great Plains lying between the Mississippi and the Rocky Mountains are not within the sweep of the Gulf winds, whose trend is SW to NE; while they are equally out of reach of moisture from the Pacific, all that having been successively deposited on the intervening mountains; hence their deficient rainfall.

Northward of the temperate zone the rainfall generally decreases as we approach the arctic regions; except where the influence of warm ocean currents to windward creates comparatively local exceptions, as in the case of Norway and Alaska.

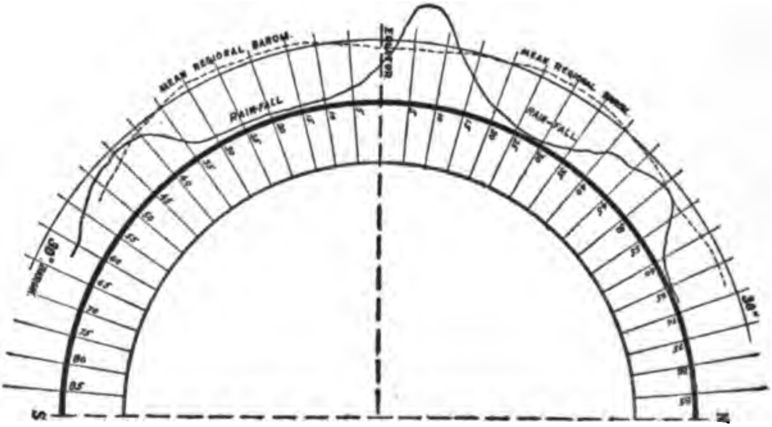

Fig. 52.—Composite Curve showing distribution of Rainfall in Europe, Africa and America projected on 100 Meridian W. L.

The general Distribution of Rainfall on the globe is well shown in the annexed diagram, which is copied by permission of the author from his treatise on the "Evolution of Climates,"[1] and represents the mean deduced from data given in the Atlas of Meteorology by J. G. Bartholomew. It is a composite curve derived from the consolidation of four curves showing the distribution of rainfall, viz, on the meridians of

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[1] "The Evolution of Climates"; by Marsden Manson, July, 1903; also *Amer Geologist*, Aug.-Oct. 1897.

20°E.L.; the west coasts of Europe and Africa; the 30th meridian W.L., in the Atlantic Ocean; and the west coasts of North and South America, projected on the plane of the 100th meridian W.L. The latter curve corresponds with remarkable closeness to the mean curve here given. "It is not intended that these curves should include the rainfall upon meridians on which the distribution in belts is interrupted by continental influences, and by the irregular oblique belts of rain on the east coasts." But it presents an admirable generalization upon which, as a basis, the local disturbances may be studied.

It will be noted that the maximum of rainfall in the tropical rain-belt lies several degrees to northward of the equator, owing doubtless to the greater land area in the northern hemisphere. There is thus, on the whole, a narrower belt of deficient rainfall or aridity between the tropical and *northern* temperate rain-belts, than in the *southern* hemisphere. The southern temperate rain-belt touches only the extreme ends of South America, Africa and New Zealand; elsewhere on the ocean it has not been sufficiently observed as yet. The zones of rainfall and aridity are, however, known to be subject to seasonal oscillations of several degrees in latitude, owing to the obliquity of the plane of the ecliptic, which shifts its position upon that of the equator.

Ocean Currents.—Since water as a fluid is subject to the same circulatory motions which cause winds, it is to be expected that ocean currents should exist corresponding to those of the air, as characterized in general above. But as water warms so much more slowly than air, its circulation would be comparatively insensible were it not for the effects produced by the air currents upon the surface of the sea, combined, as in the case of the winds, with the effects of the rotation of the earth. Without going into the details of the ocean currents in the tropics, it may suffice to say that owing partly to the moving and warming effects of winds, partly to the natural circulatory motion of the water, two great warm currents flow from the tropics northward, materially modifying what would otherwise be the climates of the coasts they touch.

The Gulf Stream.—The current most generally known is the Gulf Stream, flowing partly from the Gulf of Mexico and the Caribbean Sea, partly from outside of the same along the chain of the Lesser Antilles, along the southeast coast of the United States (Florida, Georgia and South Carolina); but owing to its greater rotational velocity it is soon, like the winds of the same latitudes, deflected from a northward to a NE. course, which carries it away from the American coast, to impart some of its warmth, (probably mainly through the winds that blow over it), to Great Britain and Ireland, Scandinavia, and Western Europe generally; while the northern American coast is left to be bathed by the icy polar current flowing from the Arctic through Baffin's Bay, which carries icebergs far to the south in the way of the transatlantic traffic between the Eastern States and Europe, and causes a difference in climate that is well exemplified in the comparison of the climate of New York with that of Naples, both lying in the same latitude; and similarly of the bleak coast of Labrador with that of Great Britain.

The Japan Stream.—On the eastern Asiatic Coast, a warm current originating in the Sunda seas, flows off the coasts of the Philippines and of China and bathes the Japanese islands; hence it is known as the Japanese Current, or Kuro-siro. It is partly this current which, failing to pass into the Arctic through the shallow waters of Behring strait, renders the coast climates of the northwest coast of America so much milder and moister than is that in corresponding latitudes on the east coasts of both continents. Alaska corresponds to Norway in its moist, foggy and relatively mild coast climate; British Columbia, Washington and Oregon participate in the benefits of the tempering influence of the return current of the Kuro-siro. But as this return ("Alaska") current passes southward into the warmer seas off the California coast, its influence is reversed; it becomes a cold current in the warm waters of the Pacific, and the warm, moist air of the ocean being carried by the westerly winds across this cold stream which flows along the shore of California, in summer dense fogs are formed, which render navigation difficult and produce a coast climate whose average summer and winter temperatures (*e. g.* at San Francisco) may differ by only a few degrees, viz., 15.5 and 13.0° C. (60 and 56° F.); so that a change of clothing from season to season is hardly called for. The Alaska Current leaves the immediate coast of California off Pt. Conception near Santa Barbara, gradually losing itself southwestward, but still tempering the tropical heat in the Hawaiian Islands. Hence the coast climate is much warmer and less foggy in southern California; but throughout the State in the interior valleys, screened from the coast winds by the Coast ranges, the temperature in summer may rise several degrees above 100° F. for days together; although, owing to the dryness of the air, the heat is not oppressive.

Contrasting Climates in N. W. America.—An even more striking contrast, showing the effects of the warm ocean and air currents, when intercepted by mountain chains, exists on the Pacific coast farther northward, as already mentioned. In Oregon and Washington first the low Coast ranges, and then the higher Cascade mountains, obstruct the eastward progress of the westerly ocean winds. The result is a very heavy rainfall to coastward of and within the Coast ranges, and an almost equally heavy precipitation on the western slope of the Cascades. Standing on the crest of the latter in summer, one may see to westward a rolling sea of clouds, causing almost daily rains; while to eastward the eye ranges over brown or whitish, dusty plains or rolling lands, almost destitute of tree growth and quivering with heat, under a deep blue sky untroubled by clouds for months.

A somewhat similar contrast is seen in the Hawaiian islands, which are in the sweep of the subtropical northeast trade winds, and on their windward (eastern) slopes have abundant rains; while on the leeward slopes an almost arid climate prevails, calling for extended irrigation.

Continental, Coast and Insular Climates.—From what has been said above, the striking differences of climate caused by the position of any region with reference to the sea or other large bodies of water on the one hand, and to mountain chains on the other, can be readily understood; provided of course that the direction of the winds and the trend of the mountain chains be properly taken into consideration. Western coasts in the temperate and subtropical regions will have a relatively even, temperate and moist climate as compared with the interior of continents, from which the tempering influence of the sea is cut off by mountain chains. Where no such chains intervene the coast climate may extend far inland. The latter case is that of Europe, where the prevailing westerly winds, warmed by the Gulf Stream, temper the climate as far east as the borders of Russia, and northward to Norway; while to southward the warm waters of the Mediterranean and Black seas temper both heat and cold in Spain, southern France, Italy and the Mediterranean border generally. But to eastward, in Russia and Siberia, the climate becomes "continental" to an extreme degree, with very cold winters and very hot summers. The same is true of interior North America, wherever the continental divide cuts off the tempering influence of the westerly winds; Montana, the Dakotas and the Great Plains states generally being examples. The climate of the Mississippi valley, as stated before, is tempered by the winds blowing from the Gulf of Mexico, but with occasional irruptions of the continental climate (sometimes reaching as far east as the South Atlantic coast) in the forms of cold "blizzards," from which the coast climates of the Pacific and of western Europe are practically free. The Atlantic coast of North America (including the coast of the Gulf of Mexico), moreover, not unfrequently suffers from the violent cyclonic storms that originate in the Antilles and follow more or less the direction of the Gulf Stream.

Islands, differing from continents mainly in their extent, and having a relatively large proportion of coast, naturally have climates controlled essentially by the surrounding ocean. The insular or oceanic climates are therefore, as a rule, more temperate and even than are those of the nearest mainland. It is often said that the climate of western Europe is "insular"; and owing to its position under the lee of the Gulf Stream, this is eminently true of Great Britain.

Subtropic Arid Belts.—Where the surface features of the land in relation to the ocean and prevailing winds do not interpose special obstacles, we find to poleward of both tropics a climatic belt of greater or less width, in which the annual, or at least the summer rainfall is too small to maintain annual herbaceous vegetation throughout the season, even when the temperature is favorable. These two "arid" belts are best defined in Africa, where the northern one is represented by the Sahara desert, lower Egypt and Arabia, while the southern one is exemplified in the Kalahari desert, to northward of the Cape of Good Hope. The northern belt is continued into Asia Minor, Palestine, Syria and Persia, and is again manifest in northwestern India; but to eastward is stopped by the influence of the great Himalaya range. The plateau countries beyond, in Central Asia, are extremely arid, largely by reason of their high elevation.

In Australia the southern arid belt is very strongly defined. In North America, the arid belt is characteristically defined on the Pacific Coast. It embraces all but the southernmost point of the peninsula of Lower California, with about two-thirds of the State of California; thence eastward across Sonora and Arizona to New Mexico and western Texas. But here the influence of the mountain ranges and high plateaus obscures the subtropical belt as such, the arid climate continuing, east of the great Pacific ranges, through Nevada, Utah, Wyoming, Montana, Idaho, and eastern Oregon and Washington nearly to the line of British Columbia on the north, and with gradually decreasing aridity, into Colorado, Kansas, Nebraska, and the Dakotas.

In South America the rainless seaward slopes of southern Peru and northern Chile indicate the southern arid belt; but here, the great chain of the Andes intervening, the dry pampas of Argentina, and the Gran Chaco of southwestern Brazil, like the Nevada basin, though arid would naturally be referred to the moisture-condensing influence of the Andes chain, under the lee of which they lie. From this cause the region of deficient rainfall, which on the western coast ends to northward of Santiago de Chile, is east of the Andes continued much farther poleward, as in North America; reaching into Patagonia.

Utilization of the Arid Belts.—While, as already explained, the distribution of the rainfall through the year is nearly as important as its total amount, yet it is evident that even with the minimum of twenty inches of total precipitation as the measure for crop production, a very large proportion of the land of the arid region cannot, even with the most elaborate system of water conservation, be supplied with sufficient water for ordinary crops, and must be otherwise utilized, mainly for pasture purposes. This is rendered practicable to a much greater extent than might be expected, because the rapid transition from the rainy to the permanent dry season cures the standing herbage into hay, which affords good grazing during the rainless season. Moreover, the use of drought-resistant, browsing forage plants, both shrubs and trees, serves to supplement materially any deficiency in the supply of "standing hay," especially in case the rains should toward the end be unduly delayed. The same is true of the dried pods and seeds of native herbage, which in some cases (bur clover, lupins, etc.,) afford highly nutritious additions to the leafy forage.[1]

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[1] See Rept. of the U. S. Commissioner of Agriculture for 1878, pp. 486–488; Bull. Nos. 16 and 42, Wyoming Expt. Station; Bull. No. 150 Calif. Expt. Station; Bull. No. 51, Nevada Expt. Station; South Dakota Station Bulletins Nos. 40, 69, 70, 74; Kansas Expt. Station, Bulletin No. 102; New Mexico Expt. Station, Bulletin No. 18; Montana Expt. Station, Bulletin No. 30; and others.

CHAPTER XVII.

RELATIONS OF SOILS AND PLANT GROWTH TO HEAT.

The Temperature of Soils.—The rapid germination of seeds, as well as the development of plants to maturity, is essentially dependent upon the maintenance of the appropriate temperature. The temperature most favorable to germination or growth, as well as the degree of tolerance of high and low temperatures, varies greatly with different plants, governing mainly what is known as their climatic adaptation. A knowledge of these points with reference to the several crops is therefore of no mean importance to the farmer; for, to a certain extent, he can control the temperature in the soil itself, and he can mostly choose for sowing and planting, the time when the soil shall have the proper temperature for rapid germination or maturity. As a rule, it is not desirable to have either seeds or seedling plants in the ground for any length of time when the temperature is too low for active vegetation; for while they rest, other, lower organisms (fungi and bacteria), adapted to low temperatures, may continue in full activity at the expense of the vitality of the crop plant.

Water exerts controlling Influence.—Since the capacity of water for heat is approximately five times greater than that of the average soil, equal weights being considered, it follows that the temperature of soil-water must exert a controlling influence over that of the soil. Taking the case of a cubic foot of loamy soil, fully saturated with water, in which one-third of the volume may be assumed to be water: the weight of the dry soil being about eighty pounds per cubic foot, calculation shows that the amount of heat required to raise the temperature of the water contained, one degree, will be fully twice as great as for that required for the soil itself. It is thus obvious that the control of soil-temperature is largely dependent upon the control of the water-content of the same, which has been discussed in a former chapter. Even in the condition of moisture known to be most favorable to plants, viz., one-half of the maximum water capacity, the influence of the water-content upon the temperature will still be as great as that of the entire soil mass. This consideration emphasizes the importance of such control.

Cold and Warm Rains.—It is not surprising then that the occurrence of cold or warm rains or the use of cold or warm irrigation water at critical periods, may largely determine the success or failure of the crop. It is well known that the occurrence of a cold rain after vegetation has started actively in early spring, may not only destroy the season's fruit crop by preventing the setting, or thereafter causing the dropping, of the fruit, but may even, if the suppression of vegetative action be continued for some length of time, result in serious injury to, or death of trees. Widely extended disastrous experience of the kind was had in California in February and March, 1887, resulting in the death of tens of thousands of fruit trees and vines during that and the following season. It is obvious that in such a case as this the rapid draining-off of the cold water through underdrains would have materially mitigated, if not wholly prevented, such injury.

Solar Radiation.—Aside, however, from such overwhelming influences as the above, the soil temperatures are measurably controlled by the extent to which they receive and absorb the sun's heat rays, whether directly or through the mediation of the air. The direct effect of the sun's rays upon the surface is, upon the whole, the most generally potent, although warm winds may occasionally exert a very strong influence. The varying influence of the sun's rays depends primarily upon the change of seasons, which themselves result from the varying angles at which the sun's rays strike the surface; as well as upon the duration of the day. The greater or less cloudiness or fogginess of the sky, of course, exerts a decided effect in this connection.

The Penetration of the Sun's Heat into the Soil.—In the temperate regions of the earth the daily variations of temperature cease to be felt at depths ranging from two to three feet, according to the nature of the soil material and its more or less compacted condition. The monthly variations, of course, reach to greater depths; while the annual variations do not disappear in the temperate zone, *e. g.*, at Paris, Zürich and Brussels, at a less depth than seventy-five feet. At these depths of constant temperature we find approximately the same temperature as that which we can deduce from the thermometric observations as the annual mean. From similar causes the mean annual temperature of any place may be approximately deduced from the observation of the water of wells and springs derived from moderate depths. For below the level of constant annual temperature the latter begins to ascend steadily as we progress downward, owing to the interior heat of the earth.

Change of Temperature with Depth.—The following table of observations made at Brussels illustrates the decrease of annual range of temperature with depth:

At feet:	Average temperature.	Annual range.
3.25	7.2° C.	10.5° C.
15.6	13.5° C.	4.5° C.
30.8	16.4 C.	1.3° C.
75.0	17.0 C.	0.0° C.

It is interesting to compare with this record that of a well sunk by Ermann at Yakutzk, Siberia, where the mean annual temperature is—9.7 C. (14.6 F.). This temperature was found a few feet below the surface. At 50 feet the temperature was—7.2 C. (19° F.); at 145 feet—5° Cent. (23° F.) at 350 feet—.9° C. (30.8° F.) showing that the ground was below the temperature of freezing water for some distance farther down; so that the search for liquid water was abandoned.

We thus see that in the Arctic regions, owing to the presence of water in the form of ice, the melting of which impedes the access of solar heat, the level of no variation is found at the distance of a few feet below the surface, despite the great variations in temperature between the short but hot summer and the extremely cold winter. In the tropics, also, the annual temperature-variation disappears at a less depth than 2 feet, in consequence of the very slight difference between the two seasonal extremes of temperature.

Surface—Conditions that influence Soil-Temperature. Among these *color* has already been mentioned, and to a certain extent discussed. While it is true that, broadly speaking, dark-colored soils absorb more of the sun's heat than light-colored ones, other things being equal, it must still be understood, that the nature of the color-giving substance exerts a very material influence upon the amount of heat absorbed. Thus charcoal is among all known substances the one absorbing and radiating the sun's heat rays most powerfully, and all kinds alike; so much so, that its absorbent power is taken as 100. But other substances which to the eye appear equally black, have by no means the same absorbing power. The heat absorption by black humus is high, though not quite equal to that of charcoal; and many gray soils, though appearing to the eye of rather light tint, really absorb more heat than others which, to our perception, have the darker tint, but are colored by other substances. Gardeners and especially vine growers in the colder portions of Europe often take advantage of the powerful absorbing power of carbon by spreading charcoal or black slate powder over the surface of the soil where early maturity is specially desired; and slate powder is similarly used by the peasants at Chamouni to hasten the melting of the snow.

Heat of High and Low Intensity.—It must also be kept in view that the surfaces, and especially the colors that favor absorption of the intense rays of the sun, may comport themselves quite differently toward heat rays of low intensity, such as those thrown back from the soil at night when it cools. Were this otherwise, a soil that absorbs much heat in the daytime would lose it with corresponding rapidity at night. But this is true only of charcoal; in the case of most other substances, there is a material difference in favor of the retention of the heat, of low intensity, by slower radiation into a "heat-trapping" atmosphere.

Reflection vs. *Dispersion of Heat.*—Theoretically, a smooth surface reflects more heat than a rough one, and warms much more slowly by absorption; as is strikingly shown by the use of polished metal screens placed on walls to prevent their being overheated by a flue near by. In the case of soils, also, the condition of the surface affects materially the absorption of heat, but not in accordance with the above rule so far as the result is concerned. For it is found that, other things being equal, a loose or cloddy surface disperses in many directions the heat it receives, and does not permit it to penetrate by conduction to so great extent as would a more compact soil, whose smooth surface would waste less of the heat received by radiation.

King has called special attention to the difference of temperature existing between soils smoothed and compacted by a roller, and the unrolled soil having a loose surface. He found that the former at a depth of one and a half inches was as much as 5.5°C. (10°F.) warmer than the loose soil, and that even at a depth of three inches a difference as high as 3.5°C. (6.5°F.) existed between the two. He observed at the same time that the temperature of the air over the unrolled ground was considerably warmer than above the rolled, thus corroborating the differences observed in the soil itself. But at night the heat is given out more rapidly from the rolled than from the unrolled surface, the latter acting as a non-conductor and keeping the soil warmer than that of the more compact rolled land. King gives as the average difference observed between rolled and unrolled land on eight Wisconsin farms, 1.6°C. (3°F.) in favor of the rolled land between 1 and 4 p.m.

It will thus be seen that the loose tilled layer, while impeding the penetration of the sun's heat into the deeper portions of the soil during the day, on the other hand serves to retain it at night better than a more compact soil. This obviously places it within the power of the farmer to exert considerable control over the soil-temperature at critical times; restraining or favoring the access of the sun's heat in accordance with the requirements of the climate or season, as the case may be.

Influence of a Covering of Vegetation, and of Mulches.—A cover of either living or dead vegetation depresses the temperature of the soil as compared with the bare land, as elaborately shown by Wollny and Ebermeyer. In the monthly averages these differences rarely exceed .8° C. (1.5 degrees F.), and are mostly below .50° C. (1° F.), but during different parts of the day they may rise to 2.2 to 2.5° C. (4 to 4.5° F.), at 4 inches depth. In summer they are greater than at other seasons. Of course the density of the vegetation or the thickness of the mulch influences them materially. Forests exert the greatest cooling influence upon the soil, and next to these the dense herbaceous crops, such as clover, and the legumes generally.

Influence of the Nature of the Soil-Material.—Aside from the surface condition, the nature of the material itself exerts a certain influence, not only upon the rate of introduction of heat, but also upon the amount taken up. Thus quartz sand having the highest density (greatest weight per cubic foot) and also the highest capacity for heat among the usual mineral soil-ingredients, will, mass for mass, experience a smaller rise of temperature than would clay or loam soil, of less density or volume-weight, and also of lower heat-capacity. While this holds good theoretically, differences corresponding to this consideration rarely occur in nature, for the reason that the much greater influence of the mechanical condition of the soil mostly overbalances these effects. Thus Wollny has shown that while quartz is a better heat-conductor than clay, quartz cobbles or gravel will materially increase the temperature of the soil in which they are imbedded. Yet compact clay is a better conductor of heat than loose sand; hence the latter, when exposed to the intense heat of the summer sun in the desert, becomes intensely hot on the surface, yet allows of the existence of abundant moisture at a depth of ten or twelve inches; while clay in the same region, being usually in a compacted condition, will show a lower surface-temperature and will be warmer and drier at a depth at which sand will still retain abundant moisture, and be comparatively cool (See chap. 13, p. 257.) So much indeed depends upon the state of mechanical division and flocculation in which the several soils may happen to be, that a hard-and-fast statement in regard to their relations to heat cannot and should not be given, as it would only lead to disappointments and practical mistakes; the more as in all cases the moisture-condition exerts an influence predominating by far over that of the dry material itself, and this moisture-condition is subject to rapid changes, owing to intrinsic differences in the several classes of soils. Wollny states as the result of his experiments, that in summer sandy soils are warmest; then humous, lime and loam soils; while in winter humous soils are warmest, then loams; and sand coldest.

Influence of Evaporation.—In treating of the Conservation of Soil Moisture (chapter 13), the effects, conditions and control of evaporation from the soil have already been discussed from several points of view; so that a summary review of the subject must suffice in this place.

It has been stated above that in the case of an average loam soil saturated with water, the heat required to raise the temperature of the water one degree would be about twice that needed to so change the dry soil material itself. But if it is required to *evaporate* the same amount of water from the soil, nearly ten (9.667) times that amount of heat will be required; or in the case assumed, twenty times as much as would suffice to raise the temperature of the dry soil through an equal interval of temperature. While in a few cases the cooling of the soil by evaporation is desirable, in the vast majority of cases it is injurious to the progress of vegetation, and should be restricted as much as possible by the means outlined in a former chapter.

Formation of Dew.—There is, however, another aspect of evaporation from the soil which has been long misunderstood, although the true state of the case was partially recognized long ago. Dew is in common parlance said to " fall," it being supposed that, like rain, it is derived from the atmosphere. While this is partially true, inasmuch as from very moist, and notably from foggy air dew is frequently deposited on grass and foliage generally, as well as on wood and other strongly heat-radiating surfaces; yet as a matter of fact, in by far the majority of cases, as shown by H. E. Stockbridge[1] and confirmed by everyday observation, dew is formed from the vapor *rising* from the warmer soil into a colder atmosphere, and condensed on the most strongly heat-radiating surfaces near the ground, such as grass, leaves both green and dry, wood, and other objects first encountering the rising vapor. In manifest proof of this it will be noted that very heavy dews may be seen on the ground, when the roofs of houses as well as the higher shrubs and trees remain perfectly dry. In winter this may be most strikingly seen in the deposition of hoar-frost in and immediately around the cracks of plank sidewalks, whose surface remains dry.

[1] " Rocks and Soils," pp. 175–189.

Dew rarely adds Moisture.—Candid observations will convince any one, therefore, that in most cases the supposed addition to the moisture of the soil from dews is an illusion. Whatever dewdrops fall on the ground are in general simply the return to the soil of a part of what came from it; while the dew that evaporates from the bedewed leaves or other objects represents simply a delayed outgo of moisture from the soil, which for a time retards evaporation direct from the soil, and thus effects a slight saving of moisture.

But while this is measurably true of inland and especially of continental areas like the great plains of North and South America, it is also true that in deep moist valleys, and on the rainy and foggy coast regions of continents, dews are found to both fall and rise, not uncommonly to such an extent as to be equivalent to a not inconsiderable aggregate precipitation. Thus in the moist coast belt of Oregon and Washington lying west of the Cascade range of mountains, the morning dews of summer are frequently so copious that the water falls in showers from the lower trees and shrubs, so as to necessitate the use of water-proof clothing when traversing the woods in the morning, quite as much as though rain was actually falling. In hilly and more especially in mountainous regions the cold air descending from above and flowing down in the ravines will often cause a heavy condensation of dew in these, while the bordering ridges, which rise above the cold currents, remain free from dew. These descending currents as a rule not only bring no surplus moisture with them, but in their downward course become warmer by contraction and therefore relatively drier. In these cases also, therefore, the dew is purely moisture derived from the ground, which in rising encounters the cold air and is thus condensed.

The fact that dew is most commonly derived from the soil could have been foreseen from the other fact, long ascertained and known, that during the night the soil is as a rule warmer than the air above it; as has been shown by the earlier observers, as well as more specifically by Stockbridge.

Dew within the Soil.—It is obvious that whenever dew is formed above the surface of the soil, the air within the latter must be at or near its point of saturation with vapor, as in fact is usually the case a few inches below the surface. It follows that when a depression of temperature occurs within the soil, *e. g.*, at night, dew must be deposited within the soil down to the depth to which the nightly variation reaches, increasing at that depth as the vapor from the warmer soil below rises, to be in its turn condensed. There is thus formed at that level a zone of greater moisture, which may sometimes be noted in digging pits, by a deeper tint, without any corresponding variation in the nature of the soil. The daily repetition of this process, at varying depths, and its greater or less recurrence at or near the limit-levels of monthly and even annual variations, must exert a not inconsiderable influence upon the vertical distribution of moisture in the soil; which instead of being usually found in horizontal bands or zones of varying moisture-contents, is usually remarkably uniform for considerable depths, despite the fitfully recurrent additions from rains. It is at least probable that this process of dew-formation within the soil materially assists capillarity in effecting a measurably uniform vertical distribution of moisture. (See also page 207, chapter 11).

Plant-development under different Temperature—Conditions.—In the arctic regions the ground, frozen in winter to unknown depths, may thaw to only three to five feet during the summer, notwithstanding the great length and continuous sunshine of the arctic day. The shallow-rooted arctic flora develops very rapidly under the influence of the continuous daylight and heat, in the course of from five to eight weeks. The seeds of these plants must, of course, be capable of germinating at very low temperatures; and as a matter of fact, we find that both in the arctic regions and in the higher mountains, certain plants are found growing and blooming on slopes flecked with snow; each plant surrounded by a small circle of bare ground, where the snow has been melted under the influence of the dark-tinted earth and leaves. It is clear that here germination has occurred, the foliage has been formed, and the roots have been exercising their vegetable functions, in ground soaked with water practically ice-cold.

Germination of Seeds.—While wild plants of special adaptation may thrive in very low (or high) temperatures, it is also true that few of our cultivated plants will germinate, and still less grow thriftily, at such low temperatures. The limit below which most cultivated plants may be considered as remaining practically inactive lies between 4.4 and 7.2° C. (40 and 45° F.). Few tropical plants will germinate much below 23.8° (75° F.) and in some cases not below 35° Cent. (95° F.). Even maize and pumpkins, according to Haberlandt, germinate most rapidly between 35 and 38.3° C. (95 and 101° F.), while for wheat, rye, oats and flax the best temperature for germination lies between 21.1 to 26.1 (70 to 79°). Under the most favorable conditions of temperature and moisture, some small seeds which readily absorb moisture will germinate in from twenty-four to forty-eight hours, while at a lower temperature they may require from three days to two weeks. Thus Haberlandt found that while oats would germinate in two days at a temperature of 17.2 to 17.5° C. (63° to 63.5°), it took a full week for germination when the temperature was only 5° C. (41° F.). It is obvious that seeds remaining inert in the soil for such lengths of time will be subject to a variety of vicissitudes that may injure or destroy their vitality. There are many bacteria and fungous parasites which at low temperatures are perfectly capable of attacking and destroying the water-soaked seed. There is thus for each plant, from the lowest to the highest, a certain temperature most favorable to development; and both above and below this, the vegetative activity is seriously interfered with or wholly checked. A knowledge of these limits is manifestly of the utmost practical importance.

The influence of too high a temperature in preventing the germination of cinchona seed from India, was curiously exemplified when it was subjected to a supposedly favorable steady temperature of 23.8°C. (75°F.) under otherwise most favorable conditions. Not a single one came up in the course of six weeks, and the box in which it had been sown was put away outside of the hothouse as a failure. Within two weeks a full stand of seedlings was obtained, at temperatures ranging between 12.7 and 15.5°C. (55° and 60°F.). The fact that the cinchona is a tree of the lower slopes of the Andes (three to five thousand feet) although at home strictly within the tropics, explains the apparent anomaly.

PART THIRD.

CHEMISTRY OF SOILS.

CHAPTER XVIII.

THE PHYSICO-CHEMICAL INVESTIGATION OF SOILS IN RELATION TO CROP PRODUCTION.

THE chemical constituents of soils have been incidentally mentioned and discussed above, both in connection with the processes of soil-formation, and with the minerals that mainly participate therein. The manner of their occurrence and their relations to plant life, so far as known, must now be considered more in detail.

HISTORICAL REVIEW OF SOIL INVESTIGATION.

While the obvious importance of the physical soil-conditions has long ago rendered them subjects of close study by Schübler [1] Boussingault and others, the chemistry of soils was very generally neglected for a considerable period, after the hopes at first entertained by Liebig that chemical analysis would furnish a direct indication and measure of soil fertility, had been sorely disappointed in respect to the only soils then investigated, viz., the long-cultivated ones of Europe. The results of chemical analysis sometimes agreed, but as often pointedly disagreed, with cultural experiences; so that after the middle of the nineteenth century, but few thought it worth while to occupy their time in chemical soil analysis.

Popular Forecasts of Soil Values.—In newly-settled countries, and still more in those yet to be settled, the questions of the immediate productive capacity, and the future durability of the virgin land are the burning ones, since they determine the future of thousands for weal or woe. This need has long ago led to approximate estimates made on the part of the settler,

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[1] The early work of Schübler on soil physics, published at Leipzig in 1838 under the title of "Grundsätze der Agrikulturchemie" and now almost inaccessible outside of old libraries, is remarkable as having anticipated very definitely much that has since been brought forward and elaborated anew. He is really the father of agricultural physics.

by the *observation of the native growth, especially the tree growth;* and where this consists of familiar species, normally developed, such estimates on the part of experienced men, based on previous cultural experience, are generally very accurate; so much so that in many of the newer states they have been adopted in determining not only the market value, but also the tax rate upon such lands, their productiveness, and probable durability being a matter of common note.

Thus in the long-leaf pine uplands of the Cotton States, the scattered settlements have fully demonstrated that after two or three years cropping with corn, ranging from as much as 25 bushels per acre the first year to ten and less the third, fertilization is absolutely necessary to farther paying cultivation. Should the short-leaved pine mingle with the long-leaved, production may hold out for from five to seven years. If oaks and hickory are superadded, as many as twelve years of good production without fertilization may be looked for by the farmer; and should the long-leaved pine disappear altogether, the mingled growth of oaks and short-leaved pine will encourage him to hope for from twelve to fifteen years of fair production without fertilization.

Corresponding estimates based upon the tree growth and in part also upon minor vegetation, are current in the richer lands also. The "black-oak and hickory uplands," the "post-oak flats," "hickory bottoms," "gum bottoms," "hackberry hammocks," "post-oak prairie," "red-cedar prairie," and scores of other similar designations, possess a very definite meaning in the minds of farmers and are constantly used as a trustworthy basis for bargain and sale, and for crop estimates. Moreover, experienced men will even after many years' cultivation be able to distinguish these various kinds of lands from one another.

Cogency of Conclusions based upon Native Growth.—Since the native vegetation normally represents the results of secular or even millennial adaptation of plants to climatic and soil-conditions, this use of the native flora seems eminently rational. Moreover, it is obvious that if we were able to interpret correctly the meaning of such vegetation with respect not only to cultural conditions and crops, but also as regards the exact physical and chemical nature of the soil, so as to recognize the *causes* of the observed vegetative preferences: we should be enabled to project that recognition into those cases where native vegetation is not present to serve as a guide; and we might thus render the physical and chemical examination of soils as useful practically, *everywhere,* as is, locally, the observation of the native growths. To a certain extent, such knowledge would be useful in determining the salient characters of cultivated soils, also; and would be the more useful and definite in its practical indications the more nearly the cultural history of the land is known, and the less the latter has been changed by fertilization. For, so soon as the first flush of production has passed, the question of how to fertilize most effectually and cheaply demands solution.

It was from this standpoint, suggested by his early experience in the Middle West and subsequently most impressively presented to him in the prosecution of the geological and agricultural survey of Mississippi, that the writer originally undertook, in 1857, the detailed study of the physical characters and chemical composition of soils. It seemed to him incredible that the well-defined and practically so important distinctions based on natural vegetation, everywhere recognized and continually acted upon by farmers and settlers, should not be traceable to definite physical and chemical differences in the respective lands, by competent, comprehensively-trained scientific observers, whose field of vision should be broad enough to embrace concurrently the several points of view—geological, physical, chemical and botanical—that must be conjointly considered in forming one's judgment of land. Such trained observers should not merely do as well as the "untutored farmer," but a great deal better.

"Ecological" studies.—Yet thus far we vainly seek in general agricultural literature for any systematic or consistent studies of these relations. We do find "ecological" lists of trees and other plants, or "plant associations," growing in certain regions or land areas, described in some of the general terms which may refer equally well to lands of profuse productiveness, or to such as will hardly pay for taxes when cultivated. Or when the productive value is mentioned, the probable cause of such value is barely alluded to, even conjecturally, unless it be in describing the "plant formations"

as xerophytic, mesophytic or hydrophytic, upon the arbitrary assumption that moisture is the only governing factor; wholly ignoring such vitally important factors as the physical texture of the soil, its depth, the nature of the substrata, and the (oftentimes abundantly obvious) predominant chemical nature of the land. And on the other hand, we find even public surveys proceeding upon the basis of physical data alone, practically ignoring the botanical and chemical point of view, and inferentially denying, or at least ignoring, their relevancy to the practical problems of the farm. [1]

Early Soil Surveys of Kentucky, Arkansas and Mississippi. —Among the few who during the middle of the past century maintained their belief in the possibility of practically useful results from direct soil investigation, were Drs. David Dale Owen and Robert Peter, who prosecuted such work extensively in connection with the geological and agricultural surveys of Kentucky and Arkansas; and the writer, who carried out similar work in the states of Mississippi and Louisiana, with results in many respects so definite that he has ever since regarded this as a most fruitful study, and has later continued it in California and the Pacific Northwest. This was done in the face of almost uniform discouragement from agricultural chemists until within the last two decades; with occasional severe criticisms of this work as a waste of labor and of public funds.

Investigation of Cultivated Soils.—All this opposition was largely due to the prejudices engendered by the futile attempts to deduce practically useful results from the chemical analysis of *soils long cultivated,* without first studying the less complex phenomena of *virgin* soils; and these prejudices persisted longest in the United States, even though in Europe the reaction against the hasty rejection of chemical soil work had begun some time before; as is evidenced by the methods employed at the Rothamsted Experimental Farm in England, the Agricultural College of France, the Russian agronomic surveys, and at several points in Germany. In none of these cases, however, more than the purely chemical or physico-chemical standpoint was assumed; although in Russia at least,

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[1] Bull. 22, Bureau of Soils, U. S. Dept. of Agriculture.

virgin soils were easily obtainable and their native growth verifiable; and were actually in part made the subject of chemical investigation.

In the course of their work, Owen and Peter always carefully recorded the native vegetation of the soils collected; but neither seems to have formulated definitely the idea that such vegetation might be made the basis of direct correlation of soil-composition with cultural experience. Owen repeatedly expressed to the writer his conviction that such a correlation could be definitely established by close study; but early death prevented his personal elaboration of the results of his work. Peter likewise stoutly maintained to the last his conviction that soil analysis was the key to the forecasting of cultural possibilities; but not being a botanist he did not see his way to put such forecasts into definite form.

Change of Views.

In the United States as well, the ancient prejudices have now gradually given way before the urgent call for more definite information than could otherwise possibly be given to farmers by the experiment stations, most of whose cultural experiments, made without any definite knowledge of the nature of the soil under trial, were found to be of little value outside of their own experimental fields. Even the multiplication of culture stations in several states, unaccompanied by soil research, is found to be a delusive repetition of the same inconclusive, random experimenting, since it takes into consideration only the climatic differences, but leaves out of consideration the potent factors of soil quality and soil variations. At most these were usually mentioned by them in such indefinite terms as " a clay loam," " a coarse sandy soil," " gray sediment land," and the like; frequently not even with a statement of the depth and character of the subsoil and substrata, much less of their geological derivation or correlations. Thus any one not happening to be personally acquainted with the land in question would be wholly without definite data to correlate the results with his own case. It is quite obvious that even if only to make possible the identification of new lands with others that have already fallen under cultural experience, and can therefore afford useful indications to the new settler, a close physical and chemical characterization of lands should be made the special object of study by the experiment stations and public surveys, particularly in the newer states.

Advantages for Soil Study offered by Virgin Lands.—Among the special advantages, then, offered by virgin soils for the study of the correlations of soils and crops, the usual existence of a native flora, representing the results of secular adaptation, is of fundamental importance. As it is at this time still historically known of most lands west of the Alleghenies what was their original timber growth, it is clear that their original condition can still be ascertained by comparison with uncultivated lands of similar growth, usually not very far away; and as their cultural history also is largely within the memory of the living generation, the behavior of such lands under cultivation is known or verifiable. Foremost among the data thus ascertainable is the *duration of satisfactory crop production, and its average amount.* To ascertain these surviving data by inquiry among the farming population should be among the foremost duties of those connected with soil surveys; and persons temperamentally unable to enlist the farmer's sympathy and interest in such inquiries must be considered seriously handicapped, no matter what their scientific qualifications may be. In no quest is it more literally true that there is no one from whom the earnest inquirer may not learn something worth knowing.

Practical Utility of Chemical Soil-Analysis; Permanent Value vs. *Immediate Productiveness.*—In many existing treatises so much emphasis is given to the alleged proofs of the inutility of chemical soil examination in particular, that a special controversion of these arguments seems necessary, in connection with a detailed statement of what can, and in part has been, done in that direction. Hence the often-repeated allusion, in the sequel, to points bearing on this question. Hence, also, the detailed discussion of many points which in most agricultural publications are given only passing notice.

In all these discussions the difference between the ascertainment of the *permanent-productive value of soils,* as against that of their *immediate producing capacity,* must be strictly kept in view. The former interests vitally the permanent settler or farmer; the latter concerns the immediate outlook for crop production, the "Düngerzustand" of the Germans. The methods for the ascertainment of these two factors are wholly distinct, even though the results and their causes are in most cases intimately correlated. The failure to observe this distinction accounts for a great deal of the obloquy and reproach that has in the past so often been heaped upon chemical soil-analysis and its advocates.

PHYSICAL AND CHEMICAL CONDITIONS OF PLANT GROWTH.

While it is true that plants cannot form their substance or develop healthy growth in the absence or scarcity of the chemical ingredients mentioned on page xxxi of this volume, it is also true that they cannot use these unless the physical conditions of normal vegetation are first fulfilled. Both sets of conditions are intrinsically equally important and exacting as to their fulfilment; and the farmers' task is to bring about this concurrence to the utmost extent possible. The chemical ingredients of plant-food can, however, be artificially supplied in the form of fertilizers, should they be deficient in the soil; but as has been shown in the preceding pages, it is not always possible to correct, within the limits of farm economy, physical defects existing in the land. Hence, however important is the natural richness of the soil in plant-food, *the first care should always be given to the ascertainment of the proper physical conditions in the soil, subsoil and substrata.* Without these, oftentimes, no amount of cultivation, fertilization and irrigation is effective in assuring profitable cultural results.

Condition of the Plant-food Ingredients in the Soil.—But even the abundant *presence* of the plant-food ingredients, as shown by analysis, will not avail, unless at least an adequate portion of the same exists in a form or forms accessible to plants. Of course this condition would seem to be best fulfilled by the ingredients in question being in the *water-soluble* condition. But in the first place, plants are quite sensitive to an over-supply of soluble mineral salts, as is evidenced by the injurious effects produced by the latter in saline and alkali lands. Furthermore, substances in that form would be very liable to be washed or leached out of the soil by heavy rains or irrigation, and would be lost in the country drainage. It is therefore clearly desirable that only a relatively small proportion of the useful soil-ingredients should be in the water-soluble or physically absorbed condition, but that a larger supply should be present in forms not so easily soluble, yet accessible to the solvent action which the acids of the soil and of the roots of plants are capable of exercising. This *virtually* available supply we may designate as the *reserve food-store.*

Finally, there is practically in all soils a certain proportion of the *soil-minerals in their original form,* as they existed in the rock-materials from which the soil was formed. These minerals being usually in a more or less finely divided or pulverulent condition, they are attacked much more rapidly by the chemically-acting "weathering" agencies, viz., water, oxygen, carbonic and humus acids, than when in solid masses; and thus, transformation of the inert rock-powder into the other two classes of mineral soil-ingredients progresses in naturally fertile soils with sufficient rapidity to produce, in a single season, sensible and practically important results, known as the effects of *fallowing.*

The Reserve.—The nature of these processes has been discussed in chapters 1 to 4; and it will be remembered that two of their most prominent results are the *formation of clay,* and of *zeolitic-compounds,* the latter being, as heretofore stated (pp. 36 ff) hydrous silicates of earths and alkalies, easily decomposable by acids, and also capable of exchanging part or the whole of such basic ingredients with solutions of others that may enter the soil. These zeolitic compounds therefore fulfil two important functions in the premises, viz.: a ready yielding-up of part of their ingredients to acid solvents, and a tendency to fix, by exchange, a portion or the whole of the soluble compounds that may be set free in, or brought upon the land. The first-mentioned property is of direct avail in that the soil-humus forms, and the roots of plants exude, acid solvents on their surface, and can thus draw upon the reserve store of food; the second tells in the direction of preventing the waste of water-soluble manurial ingredients supplied to, or formed in the soil. (See above, chapter 3, page 38).

The reserve food-store may then be placed under the following heads:

Hydrous or "zeolitic" silicates, from which dilute acids can take up the bases potash, soda, lime and magnesia. These silicates may be in either the gelatinous or powdery form; in the former case they may also occlude water-soluble substances.

Carbonates of lime and magnesia, which are readily dissolved by carbonated water as well as by the vegetable acids.

Phosphates of lime and magnesia, not very readily soluble in carbonated water, but more readily attacked by the acids of the soil and of plant roots; thus supplying phosphoric acid to plants. The more finely divided they are the more readily they are dissolved; some soils containing only crystalline needles of apatite (see chap. 5, p. 63) only are nevertheless poor in available phosphoric acid.

The natural phosphates of iron and alumina are practically insoluble in all solvents at the disposal of vegetation and though present in considerable amounts in some soils, (see chapter 19, page 355), may be considered as being permanently inert, and therefore not to be counted among the soil resources for plant nutrition. As yet no artificial process by which their phosphoric acid can be made available within the soil, has been discovered.

Water-soluble Ingredients.—As regards these it has already been explained that they are largely retained in the condition of purely physical adsorption, as in the case of charcoal or quartz sand, through which sea water filters and is thereby partially deprived of its salts. But these can be gradually withdrawn by washing with pure water alone, and still more easily when stronger solvents are used. Since the soil-water is always more or less charged with carbonic acid, and the roots themselves secrete carbonic as well as stronger acids in their absorption of mineral plant-food, there is no difficulty about explaining the manner in which such physically condensed ingredients are taken up.[1]

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[1] Whitney (Bull. 22, U. S. Bureau of Soils) claims on the basis of a large number of (three-minute) extractions of soils made with distilled water, that these solutions are essentially of the same composition in all soils; that all soils contain enough plant-food to produce crops indefinitely; and that the differences in production

Recognition of the Prominent Chemical Character of Soils. In a former chapter the soils formed from the several minerals and rocks have been discussed in a general manner. We can as a rule obtain some insight into the nature of any soil which we can trace to its parent rock or rocks, if we are acquainted with the composition of the latter.

Similarly, but in a much more direct manner, we can obtain a strong presumption as to the nature of any soil by determining the undecomposed minerals present in it. In all ordinary cases the presumption must be that the decomposed portion of the soil has been derived from the minerals still found in it. Of course it may happen in the case of lands derived from widely distinct and distant regions that no such characteristic minerals can be found; this is very commonly true of the soils forming the deltas of large rivers, in which sometimes the only remaining recognizable mineral is quartz in its several forms, with occasional grains of such hardy minerals as tourmaline, garnet, etc. Apart from such cases, the hand lens or the microscope permits us to recognize in most soils the minerals that have mainly contributed to their formation, thus also gaining a clew to their prominent chemical nature.

Such recognition sometimes involves, of course, a somewhat intimate knowledge of mineralogy; yet a little practice will enable almost any one to identify the more important soil-forming minerals, under the lens or microscope, according to the degree of abrasion or decomposition they may have undergone. The details of such researches lie outside of the limits of this treatise, but some general directions on the subject are given farther on.[1]

Acidity, Neutrality, Alkalinity.—A test never to be omitted

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are due wholly to differences in the moisture supply, which he claims is, aside from climate, the only governing factor in plant growth. The tables of analytical results given in Bull. 22 fail to sustain the first contention; the second is pointedly contradicted both by practical experience, and by thousands of cumulative culture experiments made by scientific observers; the third fails with the second, except of course in so far as an adequate supply of moisture is known to be an absolute condition both of plant growth, and the utilization of plant-food. It is moreover well known that it is not water alone, but water impregnated more or less with humic and carbonic acids, that is the active solvent surrounding the plant root.

[1] See Appendix B.

is that of the reaction of the soil on litmus or other test paper, to ascertain its acid, neutral or alkaline reaction. Should the latter occur quickly (by the prompt blueing of red litmus paper), " black alkali " would be indicated; but a blueing after 20 to 30 minutes means merely that a sufficiency of lime carbonate is present. An acid reaction (the reddening of blue litmus paper) of course indicates a " sour " soil (see chap. 8, page 122).

Chemical Analysis of Soils.—When the observations mentioned above give no very decisive results or inferences as to the soil's chemical character, the more elaborate processes of qualitative and quantitative chemical analysis may be called in. It would seem at first sight that these ought to yield very definite results to guide the cultivator; yet such is by no means always the case. Both the previous history of the land, and the method of anaylsis, influence materially the practical utility of the results of chemical soil analysis.

The cause of this uncertainty becomes obvious when we consider the three groups of ingredients outlined above, viz., the insoluble or unavailable, wholly *undecomposed rock minerals;* the "*reserve,*" consisting of compounds not soluble in water but soluble in or decomposable by weak acids; and the *water-soluble portion,* either actually dissolved in the water held by the soil, or held by the soil itself in (physical) absorption. While the latter portion is directly and immediately available to plants, the amounts thus held are usually quite small, and (outside of alkali lands) would rarely suffice for the needs of a crop during a growing season.[1] This demand must be materially supplemented by what can be made available from the soil minerals and the " reserve " by weathering, conjoined with the direct action of the acids secreted from the plant's root-hairs upon the soil particles to which they are attached. It is obvious that the greater or less *abundance* of the plant-food in the soil-material upon which these processes

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[1] The investigations of King (On the Influence of Soil Management upon the Water Soluble Salts in Soils and the Yield of Crops, Madison, 1903) show that from some soils at least, a sufficiency of plant-food ingredients for a season's crop may be dissolved by distilled water alone, if the soil be repeatedly leached and dried at 110°. Whether such a supply can be expected under field conditions, remains to be tested.

may be brought to bear, must essentially influence the adequacy of the plant-food thus supplied. Moreover, the greater or less extent to which these sources may have been drawn upon previously in the course of cultivation, will similarly influence that adequacy, on account of the diminution of the readily available supply.

Water-soluble and Acid-soluble Portions most Important.—It thus seems that while the undecomposed rock minerals are indicative of the nature of the soil, but not directly concerned in plant nutrition, the most direct interest attaches to the *water-soluble portion,* and the *acid-soluble* reserve. Both of these can, of course, be withdrawn from the soil by treatment with acids of greater or less strength; and it would seem that if we knew just what is the kind and strength of the acid solvent employed by each plant, we could so imitate their action as to determine definitely whether or not the soil contains an adequate or deficient supply of actually available food for the coming crop.

We Cannot Imitate Plant-root Action.—In this, however, we encounter serious difficulties. The acids secreted by the plant roots are not the only solvents active in the dissolution of plant-food; as yet we know the nature of only a few; and even these, instead of acting for a long time (season) on a relatively small number of soil particles touched by the root-hairs, can in our laboratories only be allowed to act for a short time on the entire soil-mass. Clearly, the results thus obtained cannot be a direct measure of the amount of plant-food which a plant may take up in a given time; we can only gain comparative figures. These, however, can be utilized by comparison with actual cultural experience obtained in similar cases.

Cultural experience must, of course, be the final test in all these questions; and it is generally more fruitful to investigate the causes underlying such actual practical experience, than to attempt to supply, artificially, the supposed conditions of plant growth. The latter are so complex and so difficult of control, that the results obtained by synthetic, small-scale experiments are constantly liable to the suspicion that they are partly or wholly due to other causes than those purposely supplied by the experimenter.

Analysis of Cultivated Soils.—It is also clear that in view of the inevitable complexity of the conditions governing vegetable growth, we should whenever feasible proceed from the more simple to the more complex. The failure to conform to this rule in soil investigation has been the cause of an enormous waste of energy and work bestowed, at the very outset, upon the most complex problem of all, viz., the investigation of soils long cultivated and manured; lands which, having been subject perhaps for centuries to a great and wholly indefinite variety of crops and cultural practices, had thereby become so beset with artificial conditions that without a previous knowledge of what constitutes the normal régime in natural soils, the correlation of their chemical constition, as ascertainable by our present methods, with their production under culture, became as complex a problem as that of motions of three mutually gravitating points in space. Neither can be solved by the ordinary processes of analysis, chemical or mathematical. Nevertheless, though it was at one time contended that the minute proportion of plant-food ingredients withdrawn from soils by cultivation could not be detected by quantitative analysis, numerous examples have shown that with our present more delicate methods this can in most cases be done, though not always after a single year's crop.

Methods of Soil Analysis.—The more or less incisive solvent agents used in extracting a soil for analysis will of course produce results widely at variance with each other. When fusion with carbonate of soda, or treatment with fluohydric acid is resorted to, we obtain for each soil-ingredient the sum of all the amounts contained in each of the three categories—the unchanged minerals, the zeolitic "reserve," and the water-soluble portion. It was early recognized that the results of such analyses bear no intelligible relation to the productive capacity of soils; for pulverized rocks of many kinds, or volcanic ashes freshly ejected and notoriously incapable of supporting plant growth, might be made to give exactly the same composition. The amounts of plant-food ingredients thus shown might be several hundreds or thousands of times greater than what one crop would take from the soil, and yet not an ear of grain could be produced on the material. The only case in which any useful information could be thus obtained would be that of the absence, or great scarcity, of one or more of the plant-food ingredients.

The next step was to use in soil analysis acids of such strength as to dissolve all the zeolitiç (and water-soluble) portion, leaving the unweathered soil minerals behind; it being assumed that the prolonged action of the roots and soil-solvents would in the end act similarly to the acids employed, such as chlorhydric or nitric acids.

But here also the results of analysis very commonly failed to correspond to cultural experience in the case of *cultivated* soils; which frequently failed utterly to produce satisfactory crops even when the acid-analysis had shown an abundance of plant-food ingredients. Upon this evidence, this method of soil investigation was also condemned as being of little or no practical utility; and this has ever since been a widely prevalent view.

The preferable investigation of cultivated soils was due to the fact that they are practically the only ones *available* in the countries where the study of agricultural science was then being prosecuted; and the paucity of useful results there achieved discouraged the undertaking of similar researches where, as in the United States, the materials for the investigation of the simpler cases—those of unchanged, natural or virgin soils—were readily accessible. It was not apparent on the surface that the indefinitely varied conditions introduced by long culture would inevitably cause this lack of definite correlation between the immediate productive capacity of a soil and the composition of its acid-soluble portion, and that yet the same might not be true of natural, uncultivated soils, which have all been subjected, alike, only to the natural processes of weathering, and to the annual return of nearly the whole of the ingredients withdrawn by plant growth.

Following the failure of the treatment with strong acids to yield with cultivated soils results definitely correlated with cultural experience, numerous attempts were made to gain better indications by the employment of weaker acid solvents. The pure arbitrariness of such diluted solvents was equaled by the total indefiniteness and irrelevance of the results with different soils. Only two rational alternatives seem to remain, viz., either to push the extraction to the full extent beyond which action becomes so slow as to clearly exclude any farther effective action of plant acids; or else to use the latter themselves at such strengths as by actual experiment is found to exist in their root sap. The first alternative aims to ascertain the ***permanent productive values*** of soils; the latter to test their ***immediate productive capacity***. Both alternatives are purely empirical, and derive their only claim to practical value from their accordance with practical experience (see chapter 19).

THE SOLVENT ACTION OF WATER UPON SOILS.

The almost universal solvent power of pure water has already been alluded to in chapter 2 (see p. 18), and illustrated by the analyses of drain and river waters. While these convey a general idea of the chief substances dissolved and carried off, the direct investigation of the solutions actually obtainable from the soil by longer treatment and with no more water than is compatible with the welfare of ordinary crops, necessarily gives somewhat different results. For when drains flow during or after heavy rains the water has not time to become saturated. The following data afford a clearer insight into the actual and possible solvent effects of water in the soil, and its possible adequacy to plant nutrition unaided by acid solvents.

Extraction of Soils with Pure Water.—Eichhorn and Wunder treated soils from Bonn, and from Chemnitz (Saxony) respectively for ten days and four weeks with about one-third of their weight of water; the solutions thus obtained contain in 1,000,000 parts:

	Bonn.	Chemnitz.
Silica	48.0	25.7
Potash (K_2O)	115.4	7.5
Soda (Na_2O)	11.0	30.4
Lime (CaO)	128.0	83.6
Magnesia (MgO)	38.4	37.4
Peroxid of Iron (Fe_2O_3)	Trace	11.7
Alumina (Al_2O_3)	?	?
Phosphoric acid (P_2O_5)	31.0	Trace
Sulfuric acid (SO_3)	100.2	....
Chlorid of Sodium (NaCl)	58.6	47.6

These figures differ widely in most respects from those given for drain and river waters. Potash especially is far more abundantly present in the Bonn soil solution than in the drain water, and so is phosphoric acid; while lime is not widely different. Eichhorn therefore calculates that with a reasonably adequate supply of water, these ingredients would fully suffice for a full crop of wheat. The Chemnitz soil, on the other hand, does not yield enough plant-food for more than a very small crop upon the same assumptions.

Continuous Solubility of Soil-ingredients.—It seems to be impossible to exhaust a soil's solubility by repeated or continuous leaching with water. This was demonstrated in 1863 and 1864 by Ulbricht[1] and by Schultze;[2] their general conclusions have quite lately been corroborated by King,[3] as the result of extended and very careful investigations.

Schultze experimented on a rich soil from Mecklenburg, by continuous leaching with distilled water for six days, one liter passing every twenty-four hours, with the following results.

RICH SOIL FROM MECKLENBURG (Schultze.)

1,000,000 PARTS OF EXTRACTS CONTAINED:

	Total matter dissolved.	Organic and volatile.	Inorganic.	Phosphoric acid.
First extract	535.0	340.0	195	5.6
Second do.	120.0	57.0	63	8.2
Third do.	261.0	101.0	160	8.8
Fourth do.	203.0	83.0	120	7.5
Fifth do.	260.0	82.0	178	6.9
Sixth do.	200.0	77.0	123	4.4
Total	1,579.0	740.0	839.	41.4

It thus appears that while the first extraction removed the main portion of the organic matter, the inorganic matters dissolved were not greatly diminished in subsequent leachings; and that phosphoric acid continued to come off to the last. The rich soil used in this case gave results corresponding in

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[1] Vers. Stat. V. p. 207.

[2] Ibid. VI. p. 411.

[3] Proc. Ass'n Prom. Agr. Sci. 1904.

general to these from the Bonn soil, in the previous table. From a poorer soil similarly treated by Ulbricht, described by him as a ferruginous sand from Dahme, the leaching of which was continued for thirty days in periods of three days each, with a total of forty times its weight of water, the results were as follows:

SOIL OF LOW PRODUCTION FROM DAHME (Ulbricht).

THE SEVERAL EXTRACTS CONTAINED IN 1,000,000 PARTS:

	First Extract.	Second Extract.	Third Extract.	Fourth Extract.	Fifth Extract.	Sixth Extract.
Potash	7	6	7	7	....	3
Soda	41	11	26	17	....	8
Lime	96	70	55	48	62	....
Magnesia	14	10	9	7	8	....
Phosphoric acid	trace	2	trace	1	....	....
Totals	158	99	97	80	70	11

It will be seen that there is a considerable difference both in the total amounts of matters dissolved and in the phosphoric acid taken out by the water, as compared with the rich soil treated by Schultze. The uniformity of the amounts of potash removed at the successive leachings is remarkable.

King's Results.—The same general features are again strikingly illustrated by King's results, as given in the following table. King's first leachings were always made by shaking up the soil with ten times its dry weight of water for three minutes, then after subsidence filtering the solutions through a Chamberland (porcelain biscuit) filter, and then (without evaporation) determining the ingredients dissolved, by very delicate, mostly colorimetric methods. Subsequent leachings were made by packing the soil around the filters and washing with five times the weight of water, taking about fifteen minutes each time; but drying the soil at 120 degrees C. between successive leachings.

WATER EXTRACTION OF SOILS OF LOW AND HIGH PRODUCTION,
By F. H. KING.

PARTS PER MILLION.

		Potash, K_2O.	Lime, CaO.	Magnesia, MgO.	Nitric Acid, N_2O_5.	Phosphoric Acid, P_2O_5.	Sulfuric Acid, SO_3.	Carbonic Acid, CO_2.	Chlorin, Cl_2.	Silica SiO_2.
SOILS OF LOW PRODUCTION.										
Sassafras sandy soil.	1 extraction	12.62	74.39	17.82	18.03	7.41	53.84	13.94	1	5.60
	11 extractions	218.25	135.35	147.45	21.76	64.16	203.96	221.33	2	170.20
Norfolk, North Carolina sandy soil	1 extraction	21.17	58.30	22.91	30.64	20.15	42.82	20.42	1	8.24
	11 extractions	166.08	162.98	125.00	27.11	80.34	172.42	148.52	2	122.20
Average.		192.60	149.20	136.23	24.44	72.25	126.13	184.93	2.–	146.20
SOILS OF HIGH PRODUCTION.										
Janesville, Wis. Loam.	1 extraction	25.35	135.30	51.72	55.10	16.96	125.43	29.31	2.67	40.28
	11 extractions	313.70	1120.30	500.60	51.42	418.85	592.75	472.95	0.00	414.50
Hagerst'wn, Pa. Clay loam.	1 extraction	21.73	165.25	76.88	25.72	11.51	187.59	97.09	1.67	21.17
	11 extractions	301.55	967.80	463.15	96.04	136.21	502.82	620.00	0.00	283.80
Average.		307.60	1044.05	487.88	73.73	277.03	547.79	546.48	0.00	349.15

King's observations show strikingly both the continuous solubility of the soil, and the differences between the solutions derived from soils of low and high productiveness; wholly negativing the contention of Whitney that the solutions from different soils are of practically the same composition.[1] King also calls attention to the fact, shown in other experiments made in the extraction of soils without intermediate dryings, that the amounts extracted were very much less in subsequent than in the first extraction; doubtless because the evaporation from the soil particles had carried a large proportion of soluble matters to the surface, whence it was readily abstracted by the first touch of the solvent water. At each drying not only are the soluble matters again drawn to the surface, but heating a soil even to 100° renders additional amounts of soil ingredients soluble both in water and in acids. It can scarcely be doubted that the intense heating which desert soils undergo during the warm season is similarly effective; and thus the great productiveness of these soils under irrigation, and the marvelously rapid development of the native vegetation when

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[1] Bulletin No. 22, Bureau of Soils, U. S. D. A.

rains moisten the parched soil, is in part at least accounted for by this immediate availability of a large supply of plant-food.

Composition of Janesville loam.—In connection with the above data given by King, it is interesting to note the composition of the soil in the above table yielding the highest proportions of soluble matter, when analyzed according to the method practiced by the writer (see chap. 19, p. 343). This analysis was made under the supervision of Professor Jaffa in the laboratory of the California Experiment Station by Assistant Charles A. Triebel.

Loam Soil from Janesville, Wisconsin; sample sent by Prof. F. H. King, Madison, Wis.

This soil is a light friable loam, resembling the northern Loess in color and texture; it is highly productive. It is underlaid at 5 feet by the drift gravel of that region, enclosing much calcareous material, which evidently has had a large share in the formation of this soil, just as is the case in southern Michigan.

The soil, when dried at 110° C., consisted of

CHEMICAL ANALYSIS OF FINE EARTH.

Insoluble matter	69.35
Soluble silica	10.89
Potash (KO_2)	.59
Soda (Na_2O)	.04
Lime (CaO)	.83
Magnesia (MgO)	.51
Br. ox. of Manganese (Mn_3O_4)	.08
Peroxid of Iron (Fe_2O_3	3.60
Alumina (Al_2O_3)	5.26
Phosphoric acid (P_2O_5)	.06
Sulfuric acid (SO_3)	.10
Water and organic matter	8.72
Total	100.03

It will be noted that in accordance with the interpretation of analyses of soils as given in the next chapter, this is a high-class soil in every respect, except that its content of phosphoric acid is only just above the lower limit of sufficiency. But as is also shown below, in presence of a large supply of lime even lower percentages of phosphoric acid are adequate for long-continued production (see chap. 19, pp. 354, 365). by rendering the substance more freely available; and that this is true in this case is shown by the result of King's leachings, in which this soil yields a maximum of 419 parts per million as against 80 and 64 parts in the poor soils, which at the same time yield only one fourth as much of lime. Unfortunately we have no full analyses of these other soils for comparison; although they have served as a basis of comparison for years in the Washington Bureau of Soils.

Solubility of Soil Phosphates in Water.—The solubility of the phosphate contents of soils has been elaborately investigated by Th. Schloesing fils.[1] He found in the case of a number of soils investigated by him that the amount of phosphoric acid P_2O_5 in the soil-solution ranged from less than one millionth (or one milligram per liter of water) in a poor soil, to over three milligrams in a rich one. He also found that for one and the same soil the amount so found was constant, if about a week's time were allowed for saturation. He calculates that while in general the amount of phosphoric acid capable of being supplied to the crop during a growing season of twenty-eight to thirty weeks would suffice for but few crops, the supply so afforded is in no case a negligible quantity, frequently amounting to more than half of the crop-requirements. Experiments with various crops prove that these dilute solutions are utilized by all of them, sometimes to the extent of completely consuming the content of the solution. The much smaller content of phosphoric acid in drain waters is accounted for by the lack of time for full saturation during the time that the flow lasts. Whitney, (Bureau of Soils, Bulletin 22) has extracted the soil-solution by means of the centrifuge from several soils; the contents of phosphoric acid thus found are in general of the same order as those shown in the preceding table by King, but much in excess of Schloesing's figures; notwithstanding the fact that Whitney's soils had been in contact with water for only twenty-four hours. The cause of this wide discrepancy is not clear.

Practical Conclusions from Water Extraction.—As regards the practically useful conclusions to be drawn from the extraction of soils with pure water, the data given above, and especially the results obtained by King, seem to prove that there is a more or less definite correlation between the immediate productiveness of soils and the amount and kinds of ingredients dissolved; especially in the case of phosphoric acid, the adequacy of the supply of which for immediate production

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[1] Ann. de la Sci. Agron., 2de serie tome 1, pp. 416-349; 1899.

is assumed to be thus demonstrable by many French chemists. Moreover, a number of King's results, tabulated in curves, exhibit a remarkable general parallelism of the curves showing totals of plant-food extracted by water, and actual crop production. This is the more remarkable since it is known to be, not pure water, but such as is more or less impregnated with carbonic acid at least, that is actually active in soil-solution and plant-nutrition. The farther development of this method may, it would seem, lead to definite conclusions at least in respect to the immediate productive capacity of cultivated, and perhaps also of virgin soils. But it is not likely to give any definite clew as to the *durability* of such lands.

ASCERTAINMENT OF THE IMMEDIATE PLANT-FOOD REQUIREMENTS OF CULTIVATED SOILS BY PHYSIOLOGICAL TESTS. PHYSIOLOGICAL SOIL-ANALYSIS.

As has already been stated, the quantitative analysis of cultivated soils by means of strong acids affords a presumptive insight into their immediate productiveness, and the kind of fertilizer needed to improve it, only in case of the extreme deficiency of one or several of the chiefly important plant-foods. The limits of deficiency of these in virgin soils have been discussed above; but since in cultivated soils amounts of soluble plant-food so small as to be beyond the limits of ordinary analytical determinations, when distributed through an acre-foot of soil may, when rightly applied, nevertheless produce very decided effects, the indications thus obtainable are not absolute. Thus a dressing of 150 lbs. of Chile saltpeter, containing only about 24 lbs. of nitrogen, is capable of causing the production of a full crop of wheat where otherwise, even under favorable physical conditions, only a fraction of a crop would have been harvested; *provided,* that all the other requisite ingredients were present to a sufficient extent and in available form. Yet the amount of nitrogen thus added would amount, in one acre-foot of soil to only .0008%, say eight ten-thousandths of one percent; which, with the amounts of substance usually employed in soil analysis, would be an unweighable quantity, and might easily be overlooked.

Since the amounts of potash and phosphoric acid actually taken out of the soil by one crop are in general of the same order of magnitude as the above, what is taken out by one or two crops will usually fall within the limits of analytical errors, especially of those incurred in sampling the soil. Yet that the changes caused by a number of successive crops can be proved, even by the ordinary methods, has been abundantly verified. For it seems that the losses of soil ingredients in cultivated lands exceed considerably those calculated from the actual drain represented by the crops.

Plot Tests.—There is, however, an obvious and apparently simple method by which every farmer might make his own fertilizer tests, on a small and inexpensive scale, the results of which may afterwards be put in effect on his entire land. It is to apply in proper proportions on plots (of say from one twentieth to one fortieth of an acre), the several plant-food ingredients usually supplied in fertilizers, singly as well as conjointly with each other, leaving check unfertilized plots around as well as among them. By comparison with these, the cultural results should at once determine which of the fertilizers can most advantageously be applied to the land. Such tests when carried out with all the proper precautions are often very decisive and practically successful. But they so frequently suffer from seasonal influences (such as scanty or excessive rainfall, cold or heat, etc.), inequality of soil conditions, failure to apply the fertilizers at the right time, or in the right way, the depredations of insects and birds, and other causes, that it generally takes several seasons' trial to obtain any definite results. On level lands of uniform nature and depth, they are most likely to be successful; while on undulating or hill lands it is not only very difficult to secure uniformity of soil and subsoil on areas of sufficient size, but also to prevent the washing of fertilized soil, or fertilizer in solution, from one plot to the other by the influence of heavy rains or irrigation; thus wholly vitiating the experiments. In very many cases, especially in the arid region, the results of such trials have been practically *nil,* for the reason that physical defects of the soil, and not lack of plant-food, were the cause of unsatisfactory production.

A full examination of physical conditions, as outlined in previous chapters, should *in all cases precede* the application of

N **Chile Saltpeter.**	**P** **Superphosphate.**	**N** **Tankage.**
Blank.	**P + N** **Superphosphate and Chile Saltpeter.**	**Blank.**
P + K **Superphosphate and sulfate of Potash.**	**Blank.**	**P + N + K** **Superphosphate Chile Saltpeter and Sulfate of Potash.**
Blank.	**K + N** **Sulfate of Potash and Nitrogen.**	**Blank.**
P **Bone meal.**	**K.** **Sulfate of Potash.**	**P** **Thomas Phosphate Slag.**

Scheme for Plot-tests of Fertilizers.

fertilizers; such examination will at the same time serve to determine the greater or less uniformity of soil-conditions, which is of first importance to the cogency of fertilizer tests. As a matter of fact, few farmers possess the necessary qualifications to carry out such tests successfully, since their execution requires a certain familiarity not only with the principles and methods of experimentation, but also the faculty and practice of close and reasoning observation; which, unfortunately, is not as yet a part of instruction in our schools. The experience so often had in co-operative work between experiment stations and farmers is cogent on this point.

Those desiring to do such work, however, can make use of something like the plan given above; it being understood that in the case of clay soils, the unplanted paths left between the plots should be at least two feet in width; in the case of sandy soils the distance should be not less than three feet, and more if the plots are located on a slope. The crop from each plot should if possible be weighed as a whole; but if the plot be large and the crop measurably uniform, an aliquot part, such as one fourth, may be weighed instead. In regular experimentation the crops are weighed both in the green (freshly cut) condition, and after drying. Since the dry matter is the real basis of value in the case of most field crops, its weight is the most important; as the water-content of green crops may vary considerably. But in the case of vegetables as well as fruit crops, not only must the weight of the fresh crop be determined, but it should be sorted into the " marketable " and " unmarketable " sizes and qualities. Failure to do this may vitiate the entire experiment for practical purposes.

Pot Culture Tests.—The uncertainty attending plot culture tests on account of the difficulty of controlling seasonal and other external conditions, has resulted in the extended adoption of indoor culture tests, usually conducted in zinc or " galvanized " cylinders of a size sufficient to contain from twelve to twenty or more pounds of soil. These are kept in a greenhouse whose temperature and moisture-condition can be regulated at will, and where the soil-moisture is wholly under control. For investigations of the effects of various kinds of plant-food upon vegetable development, this method has served most satisfactorily and effectually, and striking photographs of results thus obtained are seen on all hands: for which reason, to save space, they have not been introduced into this volume. It seems at first sight that the same method should serve admirably to determine the manure-requirements of soils under controlled conditions.

It must, however, be remembered that the field conditions as regards subsoil, evaporation, ascent of moisture from below, penetration and spread of roots, etc., in other words, all the physical conditions so vitally concerned in crop production, except the temperature and moisture-condition of the soil, are wholly left out of consideration in this method. Hence the application of the results so obtained to actual field conditions can only be made with great caution, and are often widely discrepant with actual experience.

The method has of late been carried to an extreme by the U. S. Bureau of Soils in the proposition to supplant the large soil-pots heretofore used by small paraffined wire-cloth baskets, 3 × 3 inches in size, in which the soil to be tested is sown with seeds which are allowed to develop only for three to five weeks; it being claimed that the development occurring during that time is quite sufficient to indicate what will be the ultimate outcome in crop production. But practical experience has long ago demonstrated that these early stages of growth cannot be relied upon to show the crop results to be expected. Yet if this minute scale of pot-culture should, on further test, prove to give truthful forecasts even in a mere majority of cases, the facility with which it may be carried out will entitle it to favorable consideration. A great deal more proof is needed on this point than the confident claims of the Bureau indicate.

CHEMICAL TESTS OF IMMEDIATE PRODUCTIVENESS.

Testing chemical soil-character by crop analysis.—Another method for the determination of immediate soil requirements has been elaborated by E. Godlewski.[1] The principle upon which this method rests is that plants growing in a soil deficient in available plant-food of any one kind will in their ash show a corresponding deficiency, or at least a minimum proportion of the same; and that in many cases, the nature of the

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[1] Zeitschr. Landw. Vers. Oesterr., 1901.

deficiency manifests itself in the form or development of the plant, so clearly as to render chemical analysis unnecessary (see below, chapter 22).

To a certain extent the latter idea has been and is constantly being utilized in practice. It is essentially involved in the habit of judging of land by its natural vegetation; and by agricultural chemists and intelligent farmers, when they check excessive growth of stems and leaf (indicating excess of nitrogen) by the use of lime or phosphates; or prescribe the use of nitrogenous manures when a superabundance of small, unmarketable fruit is produced. From the coincidence of such indications with the results of the analyses of soils and ashes, very definite and permanently valuable indications as to the proper fertilization and other treatment of the land may be deduced.

Godlewski insists strongly, and with a good deal of plausibility, upon the importance of making such trials in the open field and not merely in pots. While this is true, it is also true that such field experiments suffer from the same liability to imperfection as the "plot fertilizer-test" plan just described; viz., that the season may exert a much more powerful influence than the fertilization, and the tests may lead to wholly erroneous conclusions unless the experiments are continued for a number of years, and under skilled supervision. But when once the normal ratio between the ash ingredients for a particular soil and climatic region have been ascertained, the data will be of lasting benefit to agriculture there, and perhaps, other things being equal, to the world at large.

H. Vanderyst has discussed the entire subject of physiological soil analysis elaborately in the Revue Génerale Agronomique of Louvain, 1902–3 (Exp't St. Record, April 1904, Vol. 8, page 757) and shows in detail the conditions under which it may be successful. Among these he reckons as full a knowledge of the chemical characteristics of a soil as can be obtained by chemical analysis.

Chemical Tests of Immediately Available Plant-food.—It is scarcely doubtful that plants differ considerably in the energy of their action upon the "reserve" soil ingredients; hence no one solvent used by the analyst could represent correctly the action of plant-roots in general upon the soil, even if we could give that action the same time (a growing season) and opportunity afforded them in nature by the root-surface. We are forced to proceed empirically; and among the numerous solvents suggested for the purpose of soil extraction, that of Dyer, already mentioned, viz., a one per cent solution of citric acid, making allowance for such neutralization as may occur in the soil, has seemed to the writer to give results most largely in agreement with cultural experience. Walter Maxwell has recommended aspartic acid in lieu of citric, as approaching nearer to practical results, at least with sugar cane.

According to the investigations of Dyer, on Rothamstead soils of known productiveness or manurial condition, it appears that when the citric-acid extraction yields as much as .005% of potash and .010% of phosphoric acid, the supply is adequate for normal crop production, so that the use of the above substances as fertilizers would be, if not ineffective, at least not a profitable investment. These figures refer to the ordinary field crops of England and to soils originally fertile and well supplied with lime. It can readily be foreseen that under other climatic and soil conditions, different figures may have to be established. So far as the writer's experience goes, however, the above figures are very nearly valid for the arid climates as well; only the figures obtained for arid soils are usually far in excess of the above minimum postulates. Figures for lime and nitrogen are given in chapters 8 and 19. But the results obtained with the highly ferruginous soils of Hawaii show that under such conditions, figures far exceeding the minimum ones established by Dyer nevertheless coexist with need of phosphate fertilization.

CHAPTER XIX.

THE ANALYSIS OF VIRGIN SOILS BY EXTRACTION WITH STRONG ACIDS.

As stated already, the analysis of soils by extraction with strong acids is intended to enlighten us, not in regard to their *immediate* productiveness (the "Düngerzustand" of German agricultural chemists), but as to their ***permanent value or productive capacity.*** As has been seen in the preceding chapter, the efforts to unite investigators upon a generally applicable and acceptable method for the testing of immediate productiveness have not been very successful, and the number of methods employed in different countries and by different chemists within the same country are widely at variance, with no immediate prospect of agreement. Moreover, in most cases the effort is to combine both problems—***temporary*** and ***permanent*** productive capacity—in ***one*** method or operation; which still farther confuses the issue.

Convinced that the only way to unification lies in the direction of falling back upon a method that is based upon a natural limitation about which there can be no difference of opinion, the writer has, in following the lead of Owen and Robert Peter, endeavored to settle definitely ***the natural limit of the action of a suitable acid upon soils, and the time and strength of acid producing the maximum effect.***

Loughridge's Investigation.—Systematic work on these points was undertaken, at his suggestion, by Dr. R. H. Loughridge in 1871 and 1872. The results of this work were published in the succeeding year in the Amer. Journal of Science, and in the proceedings of the A. A. A. S. for 1873. They seem to be of sufficient general interest to be reproduced here.

The soil selected for this purpose was a very generalized one, representing large areas in the states of Kentucky, Tennessee, Mississippi and Louisiana, bordering on the east the immediate valley of the Mississippi river, and known locally as the "Table lands;" a noted cotton-producing upland region. The brown or yellow, moderately clayey loam is of great uniformity throughout its region of occurrence, and is evidently derived from such widely-spread sources that it represents no special rock or complex of rocks. Its natural growth is a mixture of oaks and hickories, strong and well-developed trees, such as any land-seeker would at once approve for settlement. Its cotton product when fresh was a 400-pound bale of cotton lint per acre. It may therefore well be considered a typical generalized soil of the humid upland of the Mississippi valley. Its physical analysis is given in chapter 6, it being No. 219 of the table on p. 98.

Strength of Acid used.—Three different strengths of acid were simultaneously employed, viz., chlorhydric of 1.10, 1.115 and 1.160 density. With these the soil was digested at steam heat in porcelain beakers covered with watch glasses for five days each, then evaporated and analyzed as usual. The results were as follows:

ANALYSIS WITH ACID OF DIFFERENT STRENGTHS.

Ingredients.	Sp. G. of Acid.		
	1.10	1.115	1.160
Insoluble residue	71.88	70.53	74.15
Soluble silica	11.38	12.30	9.42
Potash	.60	.63	.48
Soda	.13	.09	.35
Lime	.27	.27	.23
Magnesia	.45	.45	.45
Br. ox. Manganese	.06	.06	.06
Ferric Oxid	5.15	5.11	5.04
Alumina	6.84	8.09	6.22
Sulfuric acid	.02	.02	.02
Volatile matter	3.14	3.14	3.14
	100.02	100.69	99.29
Amount of soluble matter	24.00	27.02	22.27
Amount of soluble bases	13.50	14.70	12.83

It will be noted that the strongest acid produced the smallest amount of decomposition of the soil silicates, *e. g.* the silica soluble in carbonate of soda solution being 3% less than in the case of the acid of medium strength; a result possibly due to some difficultly-soluble compound formed on the surface of the soil grains. The weakest acid had a stronger solvent power; but the maximum effect was produced by the acid of 1.115 density. This being also the most readily obtainable, by simple steam distillation of acid of any other strength, the writer adopted it as best suited to the purposes of soil analysis.

To ascertain the time required for the desired action, viz., the solution of the plant-food ingredients to the extent likely to be of any avail to growing plants, digestions of the same soil were made in the same manner for periods of 1, 3, 4, 5 and 10 days, with the acid of 1.115 density. The results were as follows:

ANALYSIS AFTER DIFFERENT TIMES OF DIGESTION.

Ingredients.	No. of Days' Digestion.				
	1	3	4	5	10
Insoluble Residue	76.97	72.66	71.86	70.53	71.79
Soluble Silica	8.60	11.18	11.64	12.30	10.96
Potash	.35	.44	.57	.63	.62
Soda	.06	.06	.03	.09	.28
Lime	.26	.29	.28	.27	.27
Magnesia	.42	.44	.47	.45	.44
Br. Ox. Manganese	.04	.06	.06	.06	.06
Ferric Oxid	4.77	5.01	5.43	5.11	4.85
Alumina	5.15	7.38	7.07	7.88	7.16
Phosphoric acid	.21	.21	.21	.21	.21
Sulfuric acid	.02	.02	.02	.02	.02
Votatile matter	3.14	3.14	3.14	3.14	3.14
Total	99.63	100.68	100.55	100.69	99.80
Amount of soluble matter	19.67	24.88	25.57	27.02	24.87
Amount of soluble bases	11.05	13.68	13.91	14.49	13.68

While these results pointed clearly to the five-day period as being sufficiently effective so far as the plant-food ingredients are concerned, it was not easy to understand why a ten-day digestion should be less incisive than a five-day one. Instead of repeating the ten-day experiment, it was thought preferable to re-treat the residue from the five-day digestion for five days more. The result was that only more silica and alumina went into solution—in other words, additional clay was alone being decomposed. This being of no interest in the matter of plant nutrition, the five-day period was definitely adopted by the writer for his work; and it, together with the acid of 1.115 density, is the basis of all the results given in this volume, except where otherwise stated. There appeared to him to be no good reason for the acceptance of the arbitrary method of soil-extraction suggested by Kedzie and since adopted by the Association of Official Agricultural Chemists; the more as to do so would throw out of comparison all the previous work done by Owen, Peter, and himself and his pupils, which had already been definitely correlated with the natural conditions and with cultural experience.[1]

Virgin Soils with High Plant-food Percentages are Always Productive.—In strong contrast to the contradictory evidence deduced from the analysis, by any method, of cultivated soils when compared with cultural experience, it seems to be generally true that *virgin soils showing high percentages of plant-food as ascertained by extraction with strong acids* (such as hydrochloric, nitric, etc.), *invariably prove highly productive:* provided only that extreme physical characters do not interfere with normal plant growth, as is sometimes the case with heavy clays, or very coarse sandy lands.—*To this rule no exception has thus far been found.* The composition of some representative soils falling within this category is given in the annexed table, which at the same time conveys some idea of the proportion of acid-soluble ingredients usually found in the best class of natural soils.

Discussion of Table.—It will be noted in this table that while the total of the matters soluble in acids (inclusive of silica) ranges from a little below 50 to over 77 per cent, the total of directly important mineral plant-food ingredients (potash, lime, magnesia and phosphoric acid), constitute in moderately calcareous soils only from about 2.5 to somewhat over four per cent of the whole. Yet if all these were in available form, the supply would be abundant for many hundreds and even

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[1] While regretting to thus "secede" from the fellowship of his colleagues, the writer cannot but regret equally their voluntary decision to do over again, or lightly reject, all that had been done before in correlating soil-composition and plant-growth. He still thinks that it is idle to expect any unification, national or international, of methods of soil analysis based upon purely arbitrary prescriptions, unless previously shown to be definitely correlated with natural and cultural conditions; as is measurably the case with Dyer's method.

TABLE EXEMPLIFYING HIGH PLANT-FOOD PERCENTAGE IN SOILS.

	MISSISSIPPI.		LOUISIANA.	TEXAS.	CALIFORNIA.				
	Buckshot Soil. Yazoo Bottom. (Heavy Clay).	Black Prairie. Rankin County.	Loamy Sediment. Houma, Terrebonne parish. (Loam).	Rio Grande Bottom. Sandy Sediment.	San Diego Co. Colorado Bottom. Silt Sediment.	Riverside Co. Palm Valley. Micaceous Sandy Soil.	Tulare Co. Experiment Station. Plains Loam	Solano Co. Putah Valley. Dark Loam.	San Luis Obispo Co. Arroyo Grande Valley. Dark Loam.
Number of Sample.	390	188	240	37	506	1092	1159	110	2061
CHEMICAL ANALYSIS OF FINE EARTH.									
Insoluble matter	51.06 } 71.77	69.95 } 74.40	35.48 } 56.24	36.04 } 53.30	58.57 } 63.90	71.45	72.98	67.33 } 71.00	53.43 } 72.43
Soluble silica	20.70	4.46	20.76	17.26	5.33	5.50	6.60	3.67	19.00
Potash (K_2O)	1.10	.90	1.03	1.31	1.18	1.42	1.20	.93	.67
Soda (Na_2O)	.33	.24	.13	.22	.16	.18	.52	.12	.18
Lime (CaO)	1.35	1.04	.72	14.43	8.67	2.20	1.86	.77	2.11
Magnesia (MgO)	1.67	.91	.88	1.53	2.97	2.09	1.81	2.29	2.26
Br. ox. of Manganese (Mn_3O_4)	.12	.12	.014	.07	.03	.05	.08	.11	.06
Peroxid of Iron (Fe_2O_3)	5.82	4.77	7.10	4.09	4.14	6.68	6.86	8.01	5.23
Alumina (Al_2O_3)	10.54	7.25	15.45	9.11	8.40	5.78	5.66	9.16	7.40
Phosphoric acid (P_2O_5)	.30	.47	.15	.20	.13	.35	.10	.11	.71
Sulfuric acid (SO_3)	.02	.16	.25	.04	.15	.01	.03	.12	.22
Carbonic acid (CO_2)	....	....	....	9.91	7.82	18	....	....	1.82
Water and organic matter	7.37	10.74	18.52	?	3.34	4.29	2.54	7.12	6.63
Total	100.38	101.01	100.48	100.22	100.89	100.18	100.24	99.74	99.72
Humus	....	....	....	....	....	....	....	....	3.06
Nitrogen in Humus	....	....	....	....	....	....	....	....	22.00
Nitrogen in Soil.	....	....	....	....	....	....	....	....	.67
Hygroscopic Moisture. absorbed at 15° C	....	....	....	....	....	....	....	....	10.70

Available phos. acid	.14
Available potash	.14

thousands of crop years. For, one-tenth of one per cent in the case of the clayey soils of the preceding table would amount to about 3500 pounds per acre-foot, and to 4000 in the case of the sandy ones. Hence the amount of phosphoric acid in *e. g.*, the Mississippi delta soil from Houma would suffice for the production of about 440 crops of wheat grain (at 20 bushels per acre) if only one foot depth were drawn upon; but as the roots of grain easily penetrate to twice and half and three times that depth even in the humid region, the number might be tripled. As a matter of fact, however, that soil has produced full crops for from forty to fifty years only; yet this is considered an exceptionally long duration of profitable production without fertilization.

The first and last soils in the above list represent probably the highest types of productiveness known. The Yazoo bottom soil has produced up to one thousand pounds of cotton lint per acre when fresh, and is still producing from four to five hundred pounds after thirty years' culture. The Arroyo Grande soil of California with its extraordinary percentages of phosphoric acid and nitrogen, as well as exceptionally high proportion of available phosphoric acid and potash, has made such a record of productiveness, and high quality of the seeds produced, that it has for a number of years been excluded from competition for prizes offered by seed-producers elsewhere, in order to give other sections a chance. Both these soils are rather heavy clays, but readily tillable in consequence of their abundant lime-content. The remarkably high content of acid-soluble silica, indicating the presence of much easily available zeolitic matter, is doubtless connected with the exceptional productiveness.

Experience, then, proves that lands showing such high plant-food percentages will yield profitable harvests for a long time without fertilization, or with only such partial returns as are afforded by the offal of crops. Also that when fertilization comes to be required, instead of supplying *all* the ingredients usually constituting fertilizers, only one or two of these will as a rule be actually needed, and even these in smaller

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[1] The Rio Grande and Colorado bottom soils contain amounts of lime carbonate largely in excess of reqnirements, 2 to 3% of that compound being all that is needed to insure all the advantageous effects of lime in any soil (see this chapter, page 367).

amounts than in "poor" lands; thus materially reducing the expense of fertilization. The high production and durability of such lands therefore amply justify their higher pecuniary valuation; for which there would be no rational permanent ground if they required fertilization to the same extent as poor lands. In other words, if the entire amount of soil-ingredients removed by crops had had to be currently replaced equally in *all* cases (as is implied in the hypothesis, advanced by some, that the chemical composition of soils is of no practical consequence), the high prices which from time immemorial have been paid for black prairie and rich alluvial lands as against meagre uplands and barrens, would have been so much money wasted.

The explanation of these advantages evidently lies largely in the larger amounts of soil ingredients annually rendered available in rich soils by the fallowing effect of the atmospheric agencies, because of the generous totals present. The actual *amounts* of soil ingredients thus rendered accessible to plants, other things being equal, are evidently more or less directly *proportional to the totals of acid-soluble plant-food ingredients present.* And if this is true in cultivated lands, the inevitable conclusion is that the same must be true of virgin lands; *whose productive capacity and duration can therefore be forecast by such analyses.* It will be observed that the above data, which could be indefinitely increased by corroborative analyses, seem to establish the fact that about one per cent of acid-soluble potash, one of lime, the same, or less, of magnesia, and .15% of phosphoric acid, are thus shown to be "high" percentages of these ingredients in virgin soils.

It is not easy to see how the above conclusions can be successfully controverted; they are, moreover, thoroughly in accordance with cultural experience. Difficulties of interpretation arise mainly in the case of medium soils, which show neither very high nor very low percentages of plant-food; and which raise the question of what amount or percentage constitutes "adequacy" of each of the several substances.

Low Percentages.—On the other hand, whenever in virgin soils acid-analysis shows the presence of but a *very* small proportion of one or several of the essential ingredients, we have a valuable indication as to the one of these that will first be required to be added when production slackens.

What are " Adequate " Percentages of Potash, Lime, Phosphoric Acid and Nitrogen?—It is evident that a very critical discussion of cultural experience can alone answer this question; and at first sight such experience often appears very contradictory when compared with the results of analysis.

One of the chief causes of such apparent discrepancies is readily intelligible when we consider the differences in root-development of the same plant in different soils. In "light" or sandy lands the roots may penetrate to several times the depth attained by them in heavy clay soils. Having thus within their reach a soil-mass several times larger, and aërated to a much greater depth, it is but reasonable to expect that in deep, sandy lands plants would do equally well with correspondingly smaller percentages of plant-food than would suffice in clay soils, in which the root-range is very much more restricted. The well-known fact that the production of heavy clay lands may be increased by their intermixture with mere sand, adding nothing to their store of plant-food, emphasizes this expectation and elevates it into a maxim. On this ground alone, therefore, it is evident that the mere consideration of plant-food *percentages* found, can be a true measure of productiveness only in the case of virgin soils with *high* percentages.

Soil Dilution Experiments.—The extent to which dilution with mere " lightening " materials can be carried without impairing production, can of course be determined for concrete cases only; but the following experiment made at the California Station is a case in point:

One kilogram of the heavy but highly productive black clay soil of the experimental grounds of the University of California was used in each of five experimental cultures, each made in duplicate, in cylindrical vessels of zinc-covered (" galvanized ") sheet iron, all proportioned alike in height and diameter, but containing respectively one, two, four, five and six volumes of total soil. In the smallest was placed one kilogram of the undiluted, original soil, in the others successively the same amount of the soil thoroughly mixed with one, three, four, and five volumes of a dune sand fully extracted with chlorhydric acid, and washed with distilled water. The water-capacity of each of the mixtures was determined and the earth in the pots kept at the point of half-saturation generally admitted to be the optimum (best condition) for plant growth. Each pot was sown with ten seeds of white mustard, subsequently reduced to five plants selected for their vigor.

The ("galvanized") vegetation pots were made as nearly as possible of similar proportions in depth and width for each dilution, so as to give opportunity for the proportional development of the root systems. The photographs show the latter as nearly as practicable in their natural form, restored after washing off the adherent soil. It was of course extremely dif-

Fig. 53.—Natural Adobe Clay Soil.

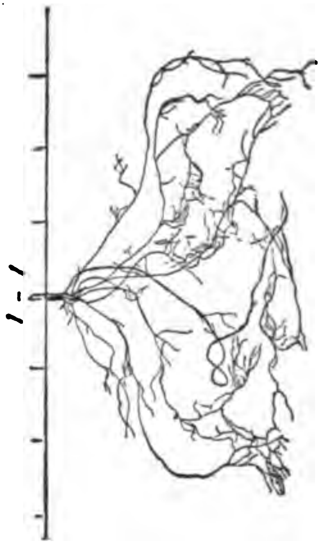

Fig. 54.—Adobe Soil diluted with Sand, 1 to 1.

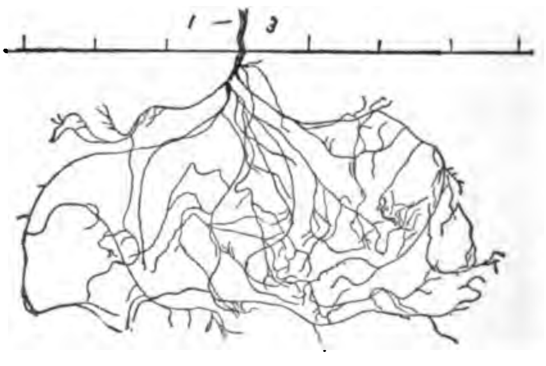

Fig. 55.—Same, diluted 1 to 3.

DEVELOPMENT OF ROOTS OF WHITE MUSTARD IN CLAY SOIL, DILUTED WITH VARIOUS PROPORTIONS OF PURE SAND.

ficult to preserve intact the extreme circumferential rootlets and hairs; yet the general development is correctly shown.

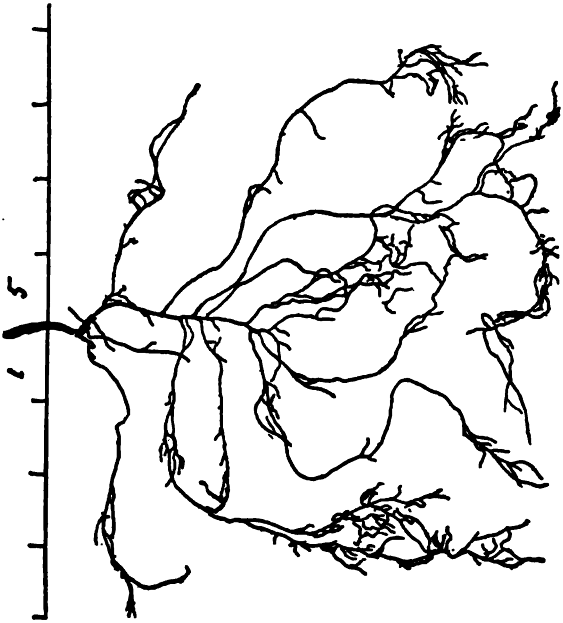

FIG. 57.—Adobe Soil diluted 1 to 5.

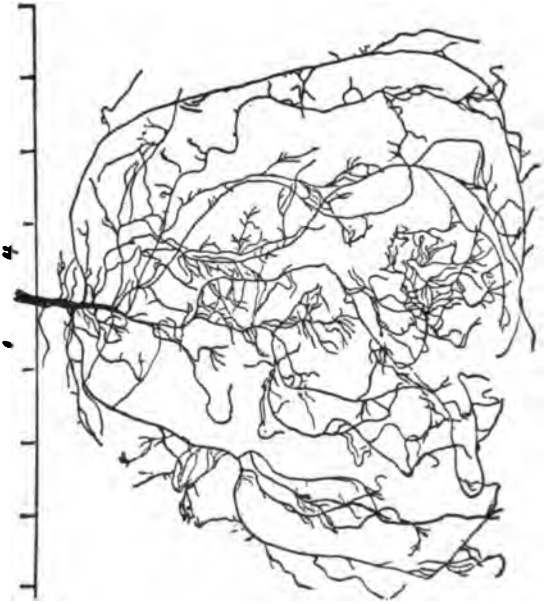

FIG. 56.—Adobe Soil diluted 1 to 4.

FIG. 58.—Soil-dilution Experiment: Photograph showing Mature Plants.

The following table shows the percentage composition of the original as well as the diluted soils, while the photographs show the development of the plants in their successive stages,

COMPOSITION OF BLACK ADOBE AND SAND DILUTIONS.

Chemical analysis of fine earth.	Original soil.	DILUTIONS.			
	1 : 0	1 : 1	1 : 3	1 : 4	1 : 5
Insoluble matter	54.50	77.25	88.62	90.00	92.42
Soluble silica	19.00	9.50	4.75	3.80	3.17
Potash (K_2O)	.73	.36	.18	.15	.12
Soda (Na_2O)	.20	.10	.05	.04	.03
Lime (CaO)	1.15	.57	.29	.23	.19
Magnesia MgO)	1.08	.54	.27	.22	.18
Br. ox. of Manganese (Mn_3O_4)	.04	.02	.01	0.1	.01
Peroxid of Iron (Fe_2O_3)	8.43	4.22	2.11	1.68	1.40
Alumina (Al_2O_3)	7.92	3.96	1.98	1.58	1.32
Phosphoric acid (P_2O_5)	.19	.10	.05	.04	.03
Sulfuric acid (SO_3)	.04	.02	.01	.01	.01
Carbonic acid (CO_2)	.....	......	......	......	......
Water and organic matter	6.54	3.27	1.64	1.31	1.09
Loss in analysis	1.18	.09	.04	.03	.03
Total	100.00	100.00	100.00	100.00	100.00
Humus	1.21	.60	.30	.24	.20
" Ash	.94	.47	.23	.19	.16
" Nitrogen, p. cent. in Humus	18.58	18.58	18.50	18.58	18.58
" " p. cent. in soil	.203	.10	.05	.04	.034

so far as these could be observed; the continued attacks of mildew and plant lice preventing full maturity being attained.

The restricted volume of soil occupied by the roots in the undiluted adobe soil, together with the very abundant development of root-hairs, is very striking. A marked change in these respects is manifest in the first dilution, and increasingly so as dilution increases; the paucity of root-hairs is very marked in the last (greatest) dilution, in which, as the photograph of the plants shows, the development was decidedly behind that in the pot containing dilution 1 : 4. The latter in fact showed the best development not only in this case, but in two other series of tests conducted at the same and subsequent times; and strangely enough, also in the pulverulent, "sandy loam" soil of the southern California substation tract. In the latter series, which for lack of space cannot be figured here, the main difference was that in the undiluted soil the roots filled the entire soil mass, instead of remaining near the surface, as in the pure adobe. It is possible that the latter was too wet when given the full half of its water-capacity, although, as the figures show, the water was slowly introduced from below by means of glass tubes, ending within a shield to prevent puddling.

Limitation of Root Action.—These results, representing five soils of different percentage-composition and physical character, but identical chemical composition and ratios between the several ingredients, and similarly acted upon by the atmospheric agencies in the past, illustrate strikingly the impossibility of judging correctly of a soil's productiveness from *percentages* of chemical ingredients alone. It is clear that the physical characters of the land as well as its depth, must be essentially taken into account. But there is obviously a certain limit beyond which greater perviousness and root-penetration cannot make up for deficiency in the absolute amounts of plant-food within possible reach of the plant; for in the case of excessive dilution these are rendered partially inaccessible within the time-limits of a season's growth.

It is hardly necessary to say that these experiments require repetition with the aid of the experience acquired in these first trials, not only in the laboratory but also in the field. It will be especially interesting to compare with the results obtained in these strongly calcareous soils. the effects of dilution in such soils as those of Florida, mentioned below; the probability being that where lime is naturally deficient, the effects of dilution will be much more pronounced in diminishing production, because of the absence of the previous favorable action of lime upon the availability of the soil-ingredients.

Lowest Limit of Plant-food Percentages and Productiveness found in Virgin Soils.—The subjoined table shows some of the very low plant-food percentages found in natural soils, all being of a sandy character:

	MISSISSIPPI SOILS.				FLORIDA SOILS.	
					Pine Lands.	
	Homochitto Bottom.	Shell Hammock.	Pine Woods.	Pine Flats.	First Class.	Second Class.
Number of Sample.	68	88	206	214	6	7
CHEMICAL ANALYSIS OF FINE EARTH.						
Insoluble matter	92.16	96.08	93.23	95.59	94.46	95.63 } 96.51
Soluble silica					1.67	.88
Potash (K_2O)	.15	.05	.26	.06	.19	.12
Soda (Na_2O)	.04	.06	.07	.05	.04	.06
Lime (CaO)	.12	.10	.12	.02	.07	.06
Magnesia (MgO)	.21	.12	.18	.07	.04	.04
Br. ox. of Manganese (Mn_3O_4)	.28	.05	.15	.05	.06	.05
Peroxid of Iron (Fe_2O_3)	1.18	.52	1.25	.46	.32	.22
Alumina (Al_2O_3)	3.22	.46	2.36	.85	.92	.47
Phosphoric acid (P_2O_5)	.08	.10	.03	.02	.11	.09
Sulfuric acid (SO_3)	.05	Trace	.02	Trace	.09	.06
Carbonic acid (CO_2)	....	....	....	....	....	....
Water and organic matter	2.70	3.02	2.33	2.28	1.88	1.81
Total	100.19	100.56	100.00	99.45	99.85	99.49

The average of plant-food percentages in all these soils is quite low, and at first sight there seems to be little choice between them. Yet two of them—Nos. 68 and 88, from Mississippi—are not only quite productive at the outset, but also fairly durable. This becomes measurably intelligible when it is known that both are of great depth, and so well drained that roots can descend for many feet; while the composition of the soil-material is almost identical for three or four feet. On the other hand, both Nos. 206 and 214 are quite shallow, being underlaid by sand almost devoid of plant-food at about two feet. In addition, both have extremely low percentages of phosphoric acid; while the rest show near .10% of that ingredient, an amount which, as will be seen hereafter, is considerably above the recognized limit of deficiency. The two Florida soils however bear only pine; they are underlaid by almost clean sand at two or three feet, and are therefore quickly exhausted. It will also be noted that their lime-percentage is only about half of that of the two first-named Mississippi soils, both of which bear a strong growth of deciduous timber trees, grape vines, and other vegetation indicating the presence of lime carbonate.

It is noteworthy, also, that the popular classification of the two Florida soils corresponds exactly with the differences in the percentages of plant-food; those in the " second-class " soil being uniformly lower than those in the one designated as first-class. This indicates, again, that *as between soils of similar character and origin, the production and durability are sensibly proportional to the plant-food percentages* when the latter fall below a certain limit; a point more fully illustrated farther on.

In the light of the above experiment and tables, it becomes pertinent to consider what *are* the lowest percentage limits of each of the more important plant-food ingredients compatible with profitable production.

LIMITS OF ADEQUACY OF THE SEVERAL PLANT-FOODS IN VIRGIN SOILS.

It is obvious that the lower limits of adequacy of the critical plant-food ingredients are best ascertained in the case of virgin soils containing very small amounts of some *one* ingredient, while fairly or fully supplied with the rest. In such cases, which are not at all infrequent, the use of the deficient ingredient as a fertilizer should produce a very marked effect so soon as the first flush of production (always noted in fresh soil) is over. This first productiveness may, even in poor lands, range from one to three years, when there is a sudden decline.

Lime a Dominant Factor.—When we investigate the cases of such lands, it soon becomes apparent that besides the low percentage of any one ingredient, the *proportions* of others present require consideration. Among these, *lime* in the form of carbonate stands foremost. Its presence exerts a dominant and beneficial influence in many respects, as is readily apparent from the prompt change in vegetation whenever it is introduced into soils deficient in it. In discussing the results of soil analysis, its consideration is of first importance in forecasting correctly the adequacy or inadequacy of other soil ingredients (see chapter 20, page 379). For in general, we find that *lower percentages of potash, phosphoric acid and nitrogen are adequate, when a large proportion of lime carbonate is present.*—This has already been referred to in connection with the table of soils of low percentages, given above. In the interpretation of results obtained by analysis this point must always be kept in view; and in the numerical statements made below, it must be understood that they refer to virgin soils sufficiently supplied with lime to assure a constant excess of lime carbonate, maintaining the conditions of nitrification and insuring the absence of acidity. (See chapter 9, page 146).

Potash.—In respect to potash, the writer was led by his early investigations in the State of Mississippi to conclude that less than one-fourth of one per cent (.25) of potash constituted a deficiency likely to call for early fertilization with potash salts; while as much as .45% of the same seemed to cause the land to respond but feebly to such fertilization. He has not found it necessary to revise materially that early conclusion, whether from his own work or from that of others. Within the last decade, Prof. Liebscher of Göttingen[1] has arrived at this identical figure from analyses made of soils upon which he had conducted a seven-year series of fertilizer tests; he having found that potash fertilization produced no sensible, or at least no paying results on land giving that figure, and otherwise well provided with plant-food. The different (lower) figures given by Schloesing, Risler and other French chemists in discussing the soils of France are doubtless due to the weak acid and short period of digestion employed in the analysis; an unfortunate discrepancy of methods which precludes any direct comparison of results.

These figures apply both to the arid and the humid regions in the temperate zones. In the tropics we find very much lower percentages quoted as adequate; thus in the laterite soils of India and Samoa,

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[1] Untersuchungen uber die Bestimmung des Düngerbedürfnisses der Ackerböden und Kulturpflanzen, von G. Liebscher; Journal für Landwirtschaft 43 (1895), Nos. 1 & 2, pp. 48–216.

according to Wohltmann, in the soils of Jamaica according to Fawcett, and in those of Madagascar according to Müntz and Rousseaux.[1] There, potash-percentages over .10% seem to be high, and in Madagascar some lands in fair production range as low as .01%. The soil-extractions have however in these cases been made with a weaker acid than above specified, so that some increase of the figures (perhaps 33 to 50%) will have to be allowed for. But even then there can be no question that a far less amount of potash, as determined by acid-extraction, is found sufficient for crop production in the tropics; doubtless because of the very intense decomposing ("fallowing") effect of the continuous heat and moisture, tending also to a rapid decomposition of organic matter and a proportionally rapid formation of carbonic and nitric acids. Such soils are of course constantly kept in a leached condition, as a result of the heavy and continuous rainfall.

Phosphoric Acid.—As regards the lower limit of adequacy of phosphoric acid, there is a remarkable agreement in the investigations made everywhere. It was placed at .05% by the writer as long ago as 1860, as the result of investigations made in the State of Mississippi; and the same figure has since been arrived at independently by agricultural chemists in France, Russia, Germany and England. The cause of this remarkable agreement is undoubtedly the readiness with which the phosphates that come under consideration at all for the nutrition of plants, are dissolved by almost any acid treatment likely to be used in soil analysis. Almost the same agreement exists in regard to the "adequacy" of .1% of P^2O^5; while all soils showing percentages between .1 and .05% are considered weak on this side, and liable to need phosphate fertilization soon. One-fourth of one per cent is an unusually high percentage in most countries; .30% and over is exceptional in non-ferruginous soils. But as stated on a previous page, a high percentage of lime carbonate may offset a smaller percentage of phosphoric acid, apparently by bringing about greater availability; and a similar effect seems to result from the presence of a large supply of humus.

On the other hand, very large percentages of finely divided ferric hydrate may, especially in the absence of lime carbonate,

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[1] *La Valeur Agricole des Terres de Madagascar.* Ann. de la Science Agronomique, 2'me serie, tome 1, 1901.

render even large supplies of phosphoric acid inert and useless, by the formation of the totally insoluble ferric phosphate. Aluminic hydrate probably acts in a similar manner. The following table gives examples in point, as regards ferric hydrate.

HAWAIIAN SOILS SHOWING HIGH CONTENTS OF FERRIC OXID.

(Rept. Cal. Exp. Sta. 1894–5, page 27.)

	Oahu.		Hawaii.		
NUMBER OF SAMPLE.	No. 21.	No. 22.	No. 24.	No. 26.	No. 27.
Coarse Materials> 0.55^{mm}......	2.00	2.50	4.00	3.00	5.00
Fine Earth....................	98.00	97.50	96.00	97.00	95.00
CHEMICAL ANALYSIS OF FINE EARTH.					
Insoluble matter...............	15.84	14.49	26.99	28.66	21.07
Soluble Silica..................	14.07	30.37	10.26	7.35	2.68
Potash (K_2O).................	.45	.26	.40	.61	.44
Soda (Na_2O)..................	.14	.08	.26	.17	.25
Lime (CaO).....................	.26	1.04	.52	.68	.28
Magnesia (MgO)................	.65	.80	.96	1.04	.60
Br. ox. of Manganese (Mn_3O_4)..	.05	.03	.21	.20	.07
Peroxid of Iron (Fe_2O_3)........	39.05	19.68	19.10	18.23	30.10
Alumina (Al_2O_3).............	14.61	18.29	21.41	20.18	14.38
Phosphoric acid (P_2O_5)........	.19	.32	.64	.70	.97
Sulfuric acid (SO_3)........	.03	.09	.32	.21	.29
Carbonic acid (CO_2)...........	....	....	....	.....	.....
Water and organic matter......	14.18	14.59	18.60	21.65	28.60
Total....	99.52	100.04	99.67	99.61	99.73
Humus.......................	3.35	3.24	4.84	5.43	9.95
" Ash.....................	3.12	2.22	2.76	3.56	6.70
" Nitrogen, p. c. in Humus..	3.30	9.800	2.800	3.100	1.71
" " , p. c. in soil......	.112	.314	.134	.168	.17
Phosph. acid in humus ash......	.110	.166	.580	.500	.....
Soluble in 2 °/₀ Citric acid....	.004	.020	.035	.037	.025
in Nitric acid, 1.20 sp. g....	.190	.320	.640	.700	.970
in Chlorhydric acid 1.115 sp. g	.430	.350	1.600	1.280	.....
Hygroscopic moisture 15° C.....	18.50	21.25	23.07	23.14	23.81

Unavailability of Ferric Phosphate.—It will be noted that in the soils from Oahu with an overwhelming amount of ferric oxid (mostly in the form of hydrate or rust) the citric acid has taken up only an insignificant amount of phosphoric acid; nitric acid took up 40 to 50 times as much, and chlorhydric doubled even this. In the much less ferruginous Hawaiian soils, though containing more alumina, the citric acid extracted nearly ten times as much; proving that it is chiefly ferric oxid, and not the alumina as has been supposed, that causes the insolubility of phosphoric acid in soils and doubtless also in fertilizers. The very unusually high content of phosphoric acid in the Hawaiian soils, exceeding all others on record, so far as known to the writer, emphasize the effects of ferric hydrate upon soluble phosphates; while the fact that these very soils are greatly benefited by the use of phosphate fertilizers, proves that the Dyer (citric acid) method for the determination of available phosphoric acid which in soils Nos. 21 to 26 yielded results largely in excess of the established limit in European soils, cannot be successfully applied to these highly ferruginous soils. It should also be noted that the amounts of phosphoric acid found in the humus extracted by the Grandeau method is in the first two Hawaiian soils over ten times the amount extracted by citric acid, but that while they rise and fall together, no definite quantitative ratio exists between the two.

It is obvious that in such soils, fertilization with water-soluble phosphates would be likely to result in the quick partial withdrawal of the same from useful action, and that any excess not promptly taken up by the crop, is likely to become inert and useless. It will evidently be desirable to use the phosphates in the form of bone-meal or basic slag (Thomas Phosphate), which because of their difficult solubility will be acted upon but very slowly, if at all, by the ferric and aluminic hydrates.

Nitrogen.—In determining the nitrogen-content of the soil, a great variety of methods has been followed. Some include all that can be obtained by the combustion of the organic matters of soil and from the nitrates present in the same; while others, the writer among the number, believe that the mainly important source of nitrogen to the plant being the nitrification of the humus-nitrogen, the determination of the humus by the method of Grandeau, and of the nitrogen contained in it, should be the standard; the unhumified vegetable matter being of no definitely ascertainable value, and the nitrates varying from day to day and being liable to be lost by leaching at any time; therefore forming no permanent feature of the soil. Considering the variety of methods, the unanimity with which about one-tenth of one per cent (.10) has been assumed as the ordinarily adequate percentage is remarkable. In view of the extremely variable amount of nitrogen in the humus (ranging from 1.7 to nearly 22%), the amount of the latter cannot, of course, afford even an approximation to the nitrogen-content; except that as in the humid region, the nitrogen-percentage is not known to exceed about 5 or 5.5%, an approximate estimate can be made on that basis. In the arid region, according to location, the nitrogen-percentage may be from three to six times greater for a similar amount of humus. (See chap. 8, p. 135). In the writer's experience, a nitrogen-percentage of .1% in the arid region is a very satisfactory figure, indicating that the need of nitrogen-fertilization is not likely to arise for a number of years.

Nitrification of the Organic Matter of the Soil.—In order to test the question whether or not the nitrogen of the unhumified debris existing in surface soils is directly nitrifiable, the writer selected a soil which in its natural condition sustains intense nitrification, so that at some points it contains as much as 1200 pounds of sodic nitrate per acre. The composition of this soil, representing the land of the "ten-acre tract" of the southern California sub-station, is as follows:

SOIL FROM "TEN-ACRE TRACT," SOUTHERN CALIFORNIA SUB-STATION, NO. 1284.

Coarse Materials > 0.55^{mm}	1.00	
Fine Earth	99.00	
	100.00	

CHEMICAL ANALYSIS OF FINE EARTH.

Insoluble matter	62.62	70.92
Soluble silica	8.30	
Potash (K_2O)	.95	
Soda (Na_2O)	.50	
Lime (CaO)	5.07	
Magnesia (MgO)	.84	
Br. ox. of Manganese (Mn_3O_4)	.06	
Peroxid of Iron (Fe_2O_3)	6.43	
Alumina (Al_2O_3)	3.88	
Phosphoric acid (P_2O_5)	.21	
Sulfuric acid (SO_3)	.06	
Carbonic acid (CO_2)	3.66	
Water and organic matter	6.02	
Total	99.70	
Water-soluble matter, per cent	.137	
Sodic nitrate, per cent	.020	
Humus	1.99	
" Ash	1.13	
" Nitrogen, per cent. in Humus	10.30	
" " , per cent, in soil	.203	
Total Nitrogen in soil	.330	
" " in unhumified matter	.127	
Available Potash } citric method	.03	
Available Phosphoric acid } citric method		
Hygroscopic Moisture absorbed at 15° C.	5.81	

It will be noticed that this is a rather strongly calcareous soil, (nearly 9% of calcic carbonate), slightly impregnated with alkali, of which about one-ninth is saltpeter. One portion of this soil was thoroughly leached with distilled water until not a trace of nitrates could be detected in the leachings. Another portion was treated for the removal of humus according to the Grandeau method (see chapter 8, page 132); the extracted soil showed under the microscope an abundance of vegetable debris, some slightly browned as from incipient humification.

The calcic and magnesic carbonates withdrawn in the humus-extraction were then restored to the soil in the form of finely divided precipitates and thoroughly mixed in, first in the dry and then in the wet condition; the extracted soil being repeatedly wetted with turbid water from the leached soil, in order to replace and reinfect it with the nitrifying bacteria. Both soils were then spread out in flat glass dishes and placed in a wooden box containing also a similar flat dish with distilled water, upon which played the draught from the inlet pipe opening into the outer air, with outlet-holes in the cover at the opposite end; thus keeping the air within fairly moist. In addition, the soils themselves were moistened with distilled water every three days and restored to a loose condition by stirring. The whole was placed so as to maintain, during the greater part of the 24 hours, a temperature of from 30 to 35 degrees C. At intervals the samples of both soils were leached and color-titrated for their nitrate content by the picric-acid test. The results, calculated as sodic nitrate, during two years were as follows:

Nitrate formed during................	Four months.	Twelve months.	Two years.
Leached natural soil..................	.012	.0420	.061
Extracted soil.........................	None.	.0030	.0042

It will be noted that in the course of four months, nitrification had not sensibly set in in the extracted soil; while in the leached natural soil the nitrate-content had reached to three-fifths the amount originally present, and in the course of a year the nitrate-content of the latter was more than double that of the original (unleached) soil; while that in the extracted soil had only reached one-seventh of the same. At the end of two years we find a still farther increase of nitric nitrogen in both, the ratio between the two remaining about the same (1 : 14). At the same time the ratio of increase attained at first had materially diminished in the water-leached soil, probably on account of the accumulation of the niter itself.

It thus appears that although the nitrogen of the unhumified organic matter constituted about 40% of the total in the original soil, it would during the entire year have contributed only to an insignificant extent to the available nitrate-supply; while the fully humified "matière noire" contributed fourteen times as much. During the ordinary growing-season of four or five months the unhumified organic matter would have yielded practically nothing to the crop.

Functions of the unhumified Vegetable Matter.—The chief utility of the unhumified matter in the soil consists of course in its gradual conversion into true humus, in the course of which it evolves carbonic gas to act on the soil minerals; while at the same time it helps to render the soil more porous and thus facilitates the action of the aerobic bacteria, for which it serves as food. Hence the addition of vegetable matter to soils not already too "light" is always advantageous, so long as it does not introduce injurious, non-humifiable ingredients, like turpentine in the sawdust of resinous pines. But it is always advisable to first use such matter as litter for stock, in order to better prepare it for the processes of humification, under the influence of ammonical fermentation, such as occurs in the decay of green plants or animal matter. A portion of the ash ingredients also is quickly utilized by solution in the soil-water.

Matière Noire the Only Guide.—According to these results it is clear that in order to gain any tangible indications with respect to crop-bearing, it is the nitrogen in the humus proper, the *matière noire* only, that should serve as the basis; and that as a current source of nitrogen to the plant, the unhumified matter is hardly entitled to more consideration than the "insoluble silicates." For, the favorable conditions for nitrification under which the above experiment was conducted, will very rarely be even approached under field conditions.

What are the Adequate Nitrogen Percentages in the Humus? The nitrification of the *matière noire* being, apparently, the main source of plant-nutrition with that element under ordinary conditions, the question naturally arises as to what may be considered an adequate nitrogen-content of that substance, so as to permit a full supply of nitrates to the crop.

The data extant on this subject are rather scanty, and thus far have all been obtained at the California Experiment Station.[1] But they seem to be very cogent in proving that the growth of crops removed from the soil causes a rapid depletion of the nitrogen in the humus-substance, and that *so soon as the nitrogen-percentage in the same falls below a certain point, the soil becomes " nitrogen-hungry;"* so that the application of nitrogenous fertilizers is needed and is very effective. The data in the table below, as well as the figure of a culture experiment (No. 52 below), illustrate this point.

ADEQUACY AND INADEQUACY OF NITROGEN CONTENTS OF HUMUS.

Collection Number.	Kind of Soil.	Locality.	Per cent. Humus in Soil.	Per cent. Nitrogen in Humus.	Per cent. Nitrogen in Soil.[2]
6	Black Adobe.	Near Stockton, San Joaquin Co., Cal................	1.05	18.66	.196
1679	do	Virgin Soil, University Grounds, Berkeley,......	1.20	18.58	.203
1842	do	Ramie plot, Univ. Grounds, 10 years cultivated.......	1.80	4.17	.075
1841	do	Grass plot, Univ. Grounds, 10 years cultivated.......	1.65	3.40	.056
29	Dark loam.	Sugar-cane land, Maui, H. T..............	10.90	3.15	.347
27	Dark loam.	Guava-land hills, near Hilo, Hawaii Isl'd............	9.95	1.71	.170

Nos. 6 and 1679 show the usual humus- and nitrogen-percentages in the "black adobe" or "prairie" soils of California. Nos. 1842 and 1841 represent the same soil as 1679, upon which, however, ramie and ray grass had respectively been growing, without fertilization, for about ten years; showing that while the ***humus-content of the soil has increased, the nitrogen-content of the humus has decreased*** in the case of ramie by 72.78%, in that of the grass by 76.78%; reducing the land to figures commonly found in the humid region. In the case of the ramie, the partial return through the leaves has resulted in a higher humus-content,

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[1] *The Supply of Soil Nitrogen*, Rep. Cal. Expt. Station, 1892–93, page 68; ibid., 1894–95, page 28; *The Recognition of Nitrogen Hungriness in Soils*, in Bull. 47, Div. of Chemistry, U. S. Department of Agriculture, 1895; Landw. Presse, No. 53, July 1885. See also for detailed data chapter 8, page 135.

[2] Calculated upon the true humus substance (matière noire), *not* by determining total (incl. unhumified) nitrogen in the soil.

together with higher nitrogen-percentage, than in the case of the grass, which in the several cuttings annually made, caused a greater depletion in nitrogen and a smaller accession of humus. The grass was very weak in its growth and partially dying out.

No. 29, the sugar-cane land from Maui, was still in fair production, but beginning to weaken as against its first production. No. 27, the guava land from Hawaii, originally bore a luxuriant cover of wild guava, but after bearing one fair crop of seed-cane and one of ratoons, the cane planted on it "spindled up" and died so soon as the seed-cane planted was exhausted. Both the island soils, originally derived from the weathering of the black basaltic lavas of the region, were well supplied with mineral plant-food (see above, page 356), and the humus-content in both was exceptionally high; and neither was in an acid condition. The difference in their nitrogen-content, both in the totals and in the humus itself, suggested that notwithstanding the relatively high total of nitrogen in No. 27, it might be nitrogen-hungry, in view of the low percentage of the nitrogen in the humus.

Confirmatory Experiment.—A pot-culture with wheat, the results of which are shown in the figure below, fully confirm this suspicion. One kilogram of soil was used in each of two pots, one being fertilized with half a gram of Chile saltpeter.

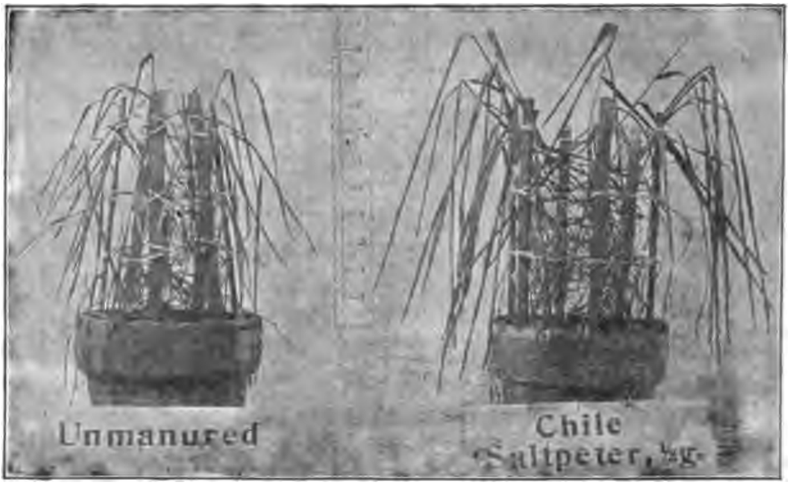

FIG. 59.—Growth of Wheat on Guava Soil from Hawaii Island.

The experiment could not be carried to full completion on account of the overwhelming invasion of mildew; but the figures speak for themselves. Moreover, a field trial made on the island with saltpeter, in pursuance of the writer's recommendation, resulted in a luxuriant growth of the cane.

Data for Nitrogen-adequacy.—It appears from the facts shown above, that for the growth of grasses a nitrogen-percentage in the humus of 1.7 is wholly inadequate, no matter how much humus may be present. A percentage of 3.15 in the Maui soil, No. 29, containing nearly 11% of humus, gave only a fair crop of sugar-cane; on the Berkeley grass plot, with 3.40% and only 1.65 of total humus, the ray grass was barely maintaining life. The ramie, with 4.17% of nitrogen in the soil-humus, was still doing fairly well.

It is doubtless impossible to give one and the same absolute figure for nitrogen-deficiency for all plants and soils. Where the conditions of nitrification are favorable, as in the presence of much of the earth carbonates, a smaller percentage may suffice for the same plants that elsewhere suffer; and it is highly probable that different minima will be found for plants of different relationship and root-habits. But there is every reason to believe that *in the nitrogen-percentage of soil-humus, considered in connection with other chemical and physical conditions and soil derivations,* we have a means of ascertaining the needs of plants with respect to nitrogen-fertilization, if proper study be given to the subject. Broadly speaking, it appears to be necessary *to keep the nitrogen-percentage of soil-humus near 4% to insure satisfactory production.*

It having been suggested that the frequent and disastrous crop failures on the noted tchernozem or black-earth soils of Russia might be due in part at least to nitrogen-depletion of the humus, the writer obtained through the courtesy of Prof. P. Kossovitch of St. Petersburg soil samples from the center of the Black-earth region, both cultivated and uncultivated. These samples are in appearance exactly like some of the dark alluvial soils of Louisiana and California, and approach them very nearly in the essentials of composition, as will be seen from the table below:

ANALYSES OF BLACK SOILS.

	Tchernozem (Russia.)		Alluvial Black clay lands.	
	Virgin.	Cultivated.	Louisiana. No. 240. Back-land Houma.	California. No. 1167. Black-land Tulare.
CHEMICAL ANALYSIS OF FINE EARTH.				
(No coarse material in soils.)				
Insoluble matter	48.38	55.09	35.48	62.43
Soluble silica	13.21	12.28	20.76	16.99
Potash (K_2O)	.72	.52	1.03	1.09
Soda (Na_2O	.20	.13	.13	.77
Lime (CaO)	1.51	1.31	.72	1.46
Magnesia (MgO)	.73	.75	.88	1.44
Br. ox. of Manganese (Mn_3O_4)	.05	.03	.01	.06
Peroxid of Iron (Fe_2O_3)	7.12	4.80	7.10	4.98
Alumina (Al_2O_3)	5.22	4.73	15.45	6.87
Phosphoric acid (P_2O_5)	.14	.13	.15	.12
Sulfuric acid (SO_3)	.07	.08	.25	.02
Carbonic acid (CO_2)	....	....	....	....
Water and organic matter	22.78	19.94	18.52	....
Total	100.13	99.79	100.48	100.59
Humus	5.11	5.54	5.07	1.33
" Ash	1.80	1.40	.91	.36
" Nitrogen, per cent. in Humus	4.63	4.22	....	....
" " per cent. in soil	.27	.24	....	....
Available Potash (citric acid method)	.014	.010	....	....
Available Phosph. acid (citric acid method)	.011	.008	.08	.01
Hygroscopic Moisture	....	12.07	18.82	5.38
absorbed at	....	17°C	13°C	15°C

It will be seen that the Russian soil is of high fertility according to the standards given above, and that the nitrogen-content of the abundant humus is amply within the limits of adequacy suggested by the experience in California and Hawaii. The humus-content of the arid California soils is characteristically low as compared with the Russian tchernozem as well as with the Houma back-land of humid Louisiana; but its nitrogen-content is doubtless at least three times that of the latter, as is that of the humus of similar lands in which it has been determined.

INFLUENCE OF LIME UPON SOIL FERTILITY.

Assuming as substantially correct the numerical data given above in respect to the three leading ingredients of plant-food —phosphoric acid, potash and nitrogen,—the dominant rôle of lime in soil fertility, already mentioned, requires some farther illustration and discussion.

" A Lime Country is a Rich Country."—The instant change of vegetation when we pass from a non-calcareous region to one having calcareous soils, has already been alluded to. (See this chapter, p. 354). But it is not necessary to be a botanist to see the change in the prosperity of the farming population as one enters a lime district. The single log-cabin with, probably, a wooden barrel terminating the mud-plastered chimney, is replaced, first by double log-houses, then by frame, and farther on by brick buildings, with the other unmistakable evidences of prosperity. Thus this is seen in passing from the mountain region of Kentucky into the "bluegrass" country, which is throughout underlaid by calcareous formations; and thus, likewise, in crossing the strike of the formations of Alabama, Mississippi and Louisiana, or any other region where underlying calcareous formations have contributed to the formation of the soils, as compared with some adjacent district where this is not the case. The calcareous loess areas bordering on the Mississippi river and some of its chief tributaries, are conspicuous cases in point, as are also the prairies of Illinois and Indiana.

Effects of High Lime-content in Soils.—The table below illustrates the fact that in the presence of high lime-percentages, relatively low percentages of phosphoric acid and potash may nevertheless prove adequate; while the same, or even higher amounts, in the absence of satisfactory lime-percentages prove insufficient for good production.[1]

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[1] This statement appears contradictory of the observations of Schloesing fils upon the solubility of phosphoric acid in presence of lime carbonate (Am. Sci. Agron., tome 1, 1899), but the natural conditions seem to justify fully the above conclusion.

SOILS SHOWING LOW PHOSPHORIC ACID PERCENTAGE.

	HIGH LIME.				LOW LIME.			
	Mississippi.	Louisiana.	California.		Mississippi.		California.	
	Kemper County.	Vernon County.	Yuba County.	Amador County.	Chickasaw County.	Carroll County.	Shasta County.	Humboldt County.
Number of Sample.	139	171	499	1113	164	48	559	207
CHEMICAL ANALYSIS OF FINE EARTH.				(Slate Soil).				
Insoluble matter	67.08	53.19 } 74.29	78.79	49.96 } 64.92	93.62 } 94.98	89.39	76.27 } 80.38	65.35 } 72.24
Soluble silica		21.10	3.80	14.96	1.36		4.10	6.90
Potash (K_2O)	.70	.33	.25	1.48	.09	.19	.50	1.13
Soda (Na_2O)	.14	.06	.04	.43	.07	.08	.04	.28
Lime (CaO)	1.37	1.40	1.02	.60	.07	.08	.10	.11
Magnesia (MgO)	1.00	.74	.40	2.21	.13	.07	.40	3.33
Br. ox. of Manganese (Mn_3O_4)	.25	.15	.02	.05	.02	.12	.01	.12
Peroxid of Iron (Fe_2O_3)	6.75	4.52	5.81	11.52	1.09	1.21	6.67	6.99
Alumina (Al_2O_3)	13.07	11.36	6.28	12.31	1.47	4.37	8.48	10.24
Phosphoric acid (P_2O_5)	.03	.05	.04	.05	.03	.05	.04	.17
Sulfuric acid (SO_3)	.08	.12	.02	.02	.01	.05	.01	.08
Carbonic acid CO_2)								
Water and organic matter	9.45	7.27	3.64	6.63	2.00	4.09	3.97	5.63
Total	99.91	100.29	100.19	100.22	99.94	99.70	100.62	100.24
Hygroscopic Moisture	11.45	18.11	4.80	5.74	1.80	4.66	5.05	7.87
absorbed at °C	8. 0	25. 5	15. 0	15. 0	11. 0	11. 0	17. 0	13. 0

Nos. 139 and 171 are heavy black prairie soils of high productive capacity, whose production had, at the time of sampling, lasted almost undiminished for over twenty years. Nearly the same is true of the two California soils, Nos. 499 and 1113; which, however, are ferruginous loams of only moderate clay-content. In all, the percentage of phosphoric acid shown by the analysis is at or below the recognized limit of deficiency, while the lime-content of all is as high as is required for the welfare of any soil, however constituted. The potash-percentage also is low in all except the "red foothill soil," No. 1113.

Passing to the soils of low lime-content, we find the two Mississippi soils, poor in both potash, lime and phosphoric acid, so low in production as to be wholly unprofitable in cultivation without previous fertilization; No. 559, from California, produced two fair crops of barley and then no more. No. 207, is the soil of Eel river bottom, California; profusely productive at first, by virtue of its high content of both potash and phosphoric acid; but "giving out" under a few years' culture of clover or alfalfa (which draw heavily upon lime), and quickly restored to productiveness under the influence of dressings of quicklime. In this case the soil had become acid, a condition which always militates against the success of culture plants, and more especially against those of the leguminous relationship.

What are Adequate Lime Percentages?—We have in the presence or absence of the natural vegetation peculiar to calcareous soils ("calciphile") an excellent index of the presence or absence of such amounts of lime carbonate as fulfil the conditions of its beneficial effects. Lists of such plants for the United States are given farther on; they agree almost throughout with such plants as are everywhere recognized by American farmers as indicating productive soils.

All soils bearing such vegetation show with red litmus paper, when wetted, a neutral reaction at first, which after the lapse of twenty or thirty minutes turns to a blue alkaline one; such as is given under the same conditions by the carbonates of lime and magnesia.

But the reverse is not necessarily true; for we occasionally find soils containing considerable amounts of lime carbonate that yet fail to bear lime vegetation. This is the case of extremely heavy clay soils, as exemplified in the table below in the case of the last three soils; while the first, No. 220, exemplifies a case where, although potash is exceptionally high, only scrubby oak growth is produced in presence of an amount of lime that in sandy lands would show profuse lime growth.

TABLE ILLUSTRATING THE NEED OF HIGH LIME-PERCENTAGES IN HEAVY CLAY SOILS.

	Mississippi.			California.
	Flatwoods, Pontotoc Co.	Hog-wallow, Jasper Co.	Ridge Prairie, Smith Co.	Yellow ridge, Alameda Co.
No. Sample	230	242	203	4
CHEMICAL ANALYSIS OF FINE EARTH.				
Insoluble matter Soluble silica	77.85	76.76	51.75	86.00
Potash (K_2O)	.75	.53	.53	.19
Soda (Na_2O)	.11	.19	.22	.15
Lime (CaO)	.18	.42	.48	.48
Magnesia MgO	.83	.67	1.01	.45
Br. ox. of Manganese (Mn_3O_4)	.17	.56	.10	.04
Peroxid of Iron (Fe_2O_3)	5.90	4.12	23.79	4.01
Alumina (Al_2O_3)	10.30	10.06	10.85	5.53
Phosphoric acid (P_2O_5)	.05	.06	.15	.06
Sulfuric acid (SO_3)	.03	.06	.02	.02
Carbonic acid (CO_2)	....	....	....	....
Water and organic matter	3.69	5.73	11.39	4.05
Total	99.86	99.17	100.29	100.99
Hygroscopic Moisture	9.3	6.8	19.7	....
absorbed at ° C	22.0	air-dry	17.0	....

All of the soils in this table are heavy clays, very difficult to till; in all, the lime-percentage falls below .5%; and none bear any lime vegetation, the Mississippi soils having a stunted growth of black jack and post oaks, such as is universally known to indicate soils too poor for profitable cultivation. The California soil bears stunted live oak (*Q. agrifolia*); but not being as heavy as its brethren from Mississippi, though unthrifty, is more readily improved.

Comparison with the two first sandy soils in the table on p. 352 shows, that with plant-food percentages equal to, or even much below those here shown, not only was vigorous lime growth present, but crop-production was good and even high.

We are thus led to the conclusion that the greater the clay percentage in a soil, the more lime carbonate it must contain in order to possess the advantages of a calcareous soil; and that while in sandy lands lime growth may follow the presence of only .10% of lime, in heavy clay soils not less than about .6% should be present to bring about the same result. This is apparent to the eye in that the dark-tinted humus characteristic of truly calcareous lands, does not appear in clay soils until the lime-percentages rise to nearly 1%; while in sandy lands a much smaller amount (say .2%) will produce this effect.

European Standards.—It is of interest to consider, in connection with preceding discussions, the estimates given by Maercker of Halle, of the practical value of soils corresponding to chemical composition as ascertained by analysis with strong acids, substantially in accordance with the methods adopted by the writer.

PRACTICAL RATING OF SOILS BY PLANT-FOOD PERCENTAGES ACCORDING TO PROF. MAERCKER, HALLE STATION, GERMANY.

Grade of Soil.	Potash.	Phosphoric Acid.	Lime.		Total Nitrogen.	Humus Nitrogen.
			Clay Soil.	Sandy Soil.		
Poor..................	Below 0.05	Below 0.05	Below .10	Below .05	Below .05	
Medium..............	0.05 — 0.15	.05 — .10	.10 — .25	.10 — .15	.05 — .10	
Normal...	0.15 — 0.25	.10 — .15	.25 — .50	.15 — .20	.10 — .15	
Good..................	0.25 — 0.40	.15 — .25	.50 — 1.00	.20 — .30	.15 — .25	
Rich..................	Above 0.40	Above .25	Above 1.00	Above .30	Above .25	
Av'age for California...	0.70	0.08	1.08			.102
" " Arid Reg...	.73	.12	1.36		.11	(?)
" " Humid Reg.	.22	.11	.11		.12	.166

It will be observed that according to Maercker's valuation, the average California soil is "rich" in potash and lime, but only "medium" as regards its contents of phosphoric acid and nitrogen. In this respect, and almost throughout, Maercker's ratings are in remarkable agreement with those made by the writer as far back as 1860.[1] It also appears that Maercker's figures for "normal" soils correspond to those of the American humid regions; the "arid" figures for potash and lime being "abnormally" high.

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[1] See discussions of analyses of Mississippi soils in the Report on the Agriculture and Geology of Mississippi, 1860; same in Rep. On Cotton Production, Tenth Census, 1880, Vol. 5; also Appendix to the Report on the Experiment Stations of the University of California, 1890, p. 163.

Unfortunately neither Maercker's method of preparing the soil extract, nor his ratings as given in the table, are accepted by all soil chemists even in Germany. As will be seen by reference to Wohltmann's work on the soils of Samoa and Kamerun (chap. 21, p. 404), his methods and numerical estimates differ widely from those given by Maercker, and also from those adopted by the Prussian soil surveys. Reference to the analyses of the soils of Madagascar by Müntz and Rousseaux, given in the same chapter, page 406, shows still another different method, although as it happens their numerical estimates do not differ very widely from those of Wohltmann. In both cases, a special, more incisive extraction is made for the determination of potash. Why the same more energetic action is not used for the other ingredients also, is not stated, and is obscure. Fortunately, in all cases the action is at least sufficiently strong to secure the dissolution of all the lime existing in the form of carbonate, and of all, or nearly all, the phosphoric acid not securely locked up as ferric phosphate; the latter being inert, is of no special interest (see Analyses of Hawaiian Soils, this chapter, page 256).

CHAPTER XX.

SOILS OF THE ARID AND HUMID[1] REGIONS.

Composition of Good Medium Soils.—In the preceding tables examples have been given of rather extreme types of soils, both rich and poor throughout, and also of such as are deficient in one or several of the important ingredients. In the table below are given the analyses of some of the good average farming lands; uplands of several states, both of the humid and arid regions. In the former, the representative timber trees of such lands are the black, red, white and (less characteristically) the post, black-jack, Spanish, overcup and locally some other oaks; grading higher in proportion to the presence of more or less hickory, and lower as the latter is replaced by pine. In the states south of Ohio, the "oak and hickory uplands" are what the farmer usually looks for, outside of the valleys or bottoms.

Criteria of Lands of the Two Regions.—In the country west of the Rocky Mountains, the timber, while locally very characteristic, cannot be as broadly used as a criterion, partly on account of its scarcity, partly because the dominant factor in the growth of trees is *moisture,* which is measurably independent of chemical soil-composition. The latter, moreover, on account of climatic conditions, already alluded to (chapter 16), does not vary as materially in the arid as the humid region, on account of the almost universal presence of larger proportions of lime carbonate; the variations of which in the humid region govern largely the vegetative changes. For we there find *the timber growth of the lowlands ascending into the uplands so*

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[1] **In the discussion in this chapter the "humid region" referred to is always that of the temperate zones, unless expressly otherwise stated. The most humid region of all—the tropics—is treated under a special head.**

UPLAND SOILS OF HUMID REGION.

	Oak Uplands with Hickory and Walnut.					Short-leaved Pine.				
State.	Tennessee.	Mississippi.		Alabama.	Georgia.	North Carolina.	South Carolina.	Mississippi.		Louisiana.
County.	Rutherford.	Pontotoc.	Benton.	Cherokee.	Polk.	Cabarrus.	Spartanburgh.	Sumner.	Franklin.	Morehouse.
Number of Sample.	7	226	216	110	502	9	5	142	71	232
Analysis of Fine Earth.										
Insoluble matter	75.35 } 82.66	83.27 } 88.83	} 83.35	78.73 } 84.77	72.32 } 76.55	78.79 } 86.19	43.74 } 49.61	90.23 } 92.55	88.75 } 90.56	81.70 } 87.45
Soluble silica	7.31 }	5.56 }	}	6.04 }	4.23 }	7.40 }	5.87 }	2.32 }	1.81 }	5.75 }
Potash (K_2O)	.26	.37	.55	.26	.73	.13	.21	.24	.14	.44
Soda (Na_2O)	.26	.22	.08	.12	.17	.01	.09	.09	.09	.27
Lime (CaO)	.34	.28	.25	.33	.29	.34	.03	.09	.07	.10
Magnesia (MgO)	.30	.23	.48	.40	.26	.31	.21	.20	.19	.24
Bro. ox. of Manganese (Mn_3O_4)	.04	.28	.76	.22	.18	.05	.01	.07	.08	.39
Peroxid of Iron (Fe_2O_3)	5.18	2.39	4.80	3.71	6.29	4.99	11.70	1.84	2.41	3.55
Alumina (Al_2O_3)	5.57	4.51	6.28	5.08	7.10	4.02	26.54	1.86	2.20	4.87
Phosphoric acid (P_2O_5)	.08	.08	.07	.09	.26	.14	.13	.09	.08	.10
Sulfuric acid (SO_3)	.08	.02	.06	.10	.11	.08	.01	.01	.01	.08
Carbonic acid (CO_2)										
Water and organic matter	5.50	3.11	4.20	5.15	6.60	3.88	11.60	2.83	4.31	2.54
Total	99.77	100.32	100.88	100.23	99.54	100.14	100.22	99.87	100.14	100.08
Humus										
" Ash										
Hygroscopic Moisture	7.29	4.08	6.84	4.50	8.71	3.65	11.21	3.57	4.4	5.47
absorbed at °C	22°C	....	....	.. ..	18°C	21.8°C	21.8°C	.11°C	....	....

UPLAND SOILS OF ARID REGION.

	CALIFORNIA.				WASHINGTON.		MONTANA.	
	Placer Co. Auburn.	San Diego Co. National City.	Ventura Co.	Riverside Co. Arlington.	Bunch grass Ritzville Ridge.	Bunch grass Selah Valley, Rolling Upland.	Judith Gap.	Near Bozeman, Allen's Ranch.
Number of Sample.	51	47	182	1406	46	37	371	387
Analysis of Fine Earth.								
Insoluble matter	} 69.52	} 86.21	74.91 } 82.84	76.41 } 84.61	76.71 } 82.00	77.18 } 81.69	74.17 } 78.80	67.28 } 73.83
Soluble silica			7.93	8.20	5.28	4.59	4.61	6.54
Potash (K_2O)	.38	.48	.62	.87	.72	.62	1.07	1.20
Soda (Na_2O)	.07	.14	.16	.29	.09	.24	.16	.21
Lime (CaO)	.96	.36	.95	1.57	1.04	1.32	.71	2.92
Magnesia (MgO)	1.09	.54	.96	1.33	.94	.92	1.16	1.44
Br. ox. of Manganese (Mn_3O_4)	.39	.10	.04	.04	.05	.05	.97	.62
Peroxid of Iron (Fe_2O_3)	12.42	3.69	5.07	4.20	5.14	5.62	4.20	4.63
Alumina (Al_2O_3)	10.97	5.12	5.94	5.30	5.74	5.24	7.08	8.09
Phosphoric acid (P_2O_5)	.16	.23	.13	.14	.16	.13	.12	.18
Sulfuric acid (SO_3)	.01	.03	.04	.01	.01	.05	.02	.01
Carbonic acid (CO_2)	....	....	....	....	....	....	....	1.76
Water and organic matter	5.14	2.60	2.67	1.60	4.58	3.52	6.54	5.37
Total	101.10	99.50	99.41	100.05	100.48	99.37	99.94	99.69
Humus	1.14	.56	1.06	.20	.90	.48	....	....
" Ash	1.12	1.04	1.00	.64	.42	.32	....	....
Hygroscopic Moisture	....	2.30	6.59	1.77	5.60	4.84	9.77	10.37
absorbed at °C	....	15	15	15	15	15	15	15

soon as the latter becomes decidedly calcareous; as is abundantly exemplified in the loess or "bluff" formations bordering the Mississippi, Ohio, and Missouri rivers, where the black walnut, tulip tree, ash, honey-locust, together with the lowland oaks, hickories and cane usually characterizing the stream bottoms, grow abundantly and with luxuriant development on the adjoining steep hill country as well (see below, chapters 24, 25).

Soils of the Humid Region.—Taking a view, first, of the table showing the soils of the *humid* region, it appears that the change of vegetation from walnut and hickory to the short-leaved pine bears no visible relation to the increase or decrease of potash or phosphoric acid, but is plainly governed mainly by the amount of lime present. Where the short-leaved pine prevails the soil is almost always either neutral or shows the alkaline reaction in the course of half an hour; but where the long-leaved pine predominates the soil has almost always an acid reaction. The latter is also usually found in bottoms in which the loblolly pine (*P. taeda*) prevails, and where, although the soil may show a fair proportion of lime in the analysis, it does not exist in the form of carbonate.

The examples here given are from lands not derived from, or underlaid by, limestone formations. Where the latter exist the percentage of lime is usually materially increased; as it is also in the lowlands or bottoms when compared with adjacent uplands (see above, chapter 10, p. 162; chapter 18, p. 331); as well as in the delta lands of rivers.

Soils of the Arid Region.—Even a cursory comparison of the soils of the arid regions of the Pacific slope with those of the humid, as given in the above tables, shows some striking points of difference. The most obvious is the uniformly high percentage of lime, and usually also of magnesia, in the arid soils, and that quite independently of underlying formations, calcareous or otherwise. This occurs despite the fact that while limestone formations are very prevalent east of the Rocky Mountains, they are quite scarce west of the same. The red (Laramie) sandstones of Wyoming, the slates of the foothills of the Sierra Nevada, the clay shales, granites and eruptives of the Coast Ranges of California, Oregon and Washington, and the varied black rocks of the great lava sheet of the Pacific Northwest, all alike produce soils of high *lime* content as compared with Eastern soils not derived from calcareous formations. This fact has already been referred to, but is more fully illustrated in the table below.

Aside from the lime-content, however, it will be noted in the preceding table that the *potash*-content of the arid soils is on the average considerably higher than in those of the humid region. In fact it is hard to find west of the Rocky Mountains (except where high elevation causes a humid climate) any soils as poor in potash as are many of the commonly cultivated lands of the Eastern United States.

Other ingredients do not show such marked differences from the purely chemical standpoint: yet, as will be shown below, the forms in which silica and alumina occur are also not inconsiderably modified.

GENERAL COMPARISON OF SOILS FROM THE ARID AND HUMID REGIONS OF THE UNITED STATES.[1]—In order to verify the conclusions just mentioned upon the broadest basis possible, the following table has been compiled from all available sources; partly published, partly in manuscript only, having remained in the writer's hands since the cessation of the Northern Transcontinental Survey, prosecuted from 1880 to 1883, under the auspices of the Northern Pacific Railroad, in Washington and Montana. The published data are derived partly from the records of State surveys, partly from the soil work connected with the Tenth Census; partly also from those of Experiment Stations. In most cases it has of course been necessary to restrict the comparison to such analyses as have been made by substantially identical methods, for reasons already given; but in the cases of some states from which numerous analyses made by the Kedzie method, adopted by the Association of Official Chemists, were available, the average has been given but the name of the state starred, to indicate that the percentages, excepting phosphoric acid, are lower than they would be if made by the method adopted by the writer, particularly as regards potash. The adoption of the one-millimeter mesh for the fine-earth sieve instead of the half-milli-

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[1] Abstracted and revised from Bulletin No. 3, U. S. Weather Bureau, 1893.

meter size also creates an unfortunate and ineliminable discrepancy.

In order to exhibit clearly the influence of climate as distinct from other local conditions, it was also necessary to eliminate, in both the arid and humid regions, the soils directly derived from, or connected with calcareous formations; such as the prairies of the Southwestern States, the Bluegrass region of Kentucky, etc. This rule having been applied impartially to the soils of both climatic regions, it can hardly be questioned that the conclusions flowing from a discussion of the results of the comparison are entitled to as much weight as are those of any comparison based on large numbers of observations made, not with reference to the special point under consideration, but with a practical object of which the governing conditions were more or less uncertain, and required to be ascertained by a process of elimination.

The table gives, first, the averages for each ingredient for each of the states represented, the number of analyses from which the averages are derived being given in each case. These averages are given separately for the states of the humid and the arid regions respectively; and at the base of each group the grand average is shown in two forms. The first gives the figures as derived from the aggregate number of soil analyses in each great group, being 696 for the humid, 178 for the transition region and 573 for the arid, divided into the totals resulting from the summation of each ingredient for the whole 696, 178 and 573, respectively.

The second form is that in which the soils of each state are considered as representative of the general character of such state, as the result of intentional selection; such as actually occurred in the cases of those included in the census work of 1880. The figures given here are therefore the result of a summation of the *state averages* as such, and of their division by the number of states represented.

It will be noted that while these two modes of presentation do change the figures a little, yet in either form the same general result is outlined with striking accuracy. It is also notable that notwithstanding the less complete extraction of soil-ingredients in the starred states, the general ratios between arid and humid soils remain substantially the same. For Western Oregon, local calcareous formations compel omission of three lime figures from the averages.

AVERAGE COMPARISON OF SOILS IN THE HUMID AND ARID REGIONS OF THE UNITED STATES.

	Number analyzed.	Insoluble Residue.	Soluble Silica.	Sum of Insoluble Residue and Soluble Silica.	Potash.	Soda.	Lime.	Magnesia.	Br. oxide Manganese.	Peroxid of Iron	Alumina.	Phosphoric Acid.	Sulfuric Acid.	Water and Organic Matter.	Hygroscopic Moisture.	Humus.	Nitrogen in Humus	Nitrogen in Soil.
HUMID REGION.																		
Rhode Island*	7	82.41	1.69	84.10	.15	.09	.43	.27	.04	3.59	3.66	.09	.10	7.43	5.23	2.59	......	......
North Carolina	20	81.63	3.50	85.13	.15	.06	.09	.08	.07	4.72	5.71	.12	.06	3.98	4.18	......	......	......
South Carolina	30	85.54	3.39	88.93	.12	.07	.07	.12	.05	2.47	4.59	.11	.06	3.39	4.22	.42	......	......
Georgia	40	86.07	2.89	88.96	.15	.07	.08	.10	.09	2.75	4.02	.11	.10	3.62	3.54	......	......	......
Florida	10	85.33	1.33	86.66	.07	.03	.09	.03	.08	.60	1.17	.08	.05	1.89	1.72	......	......	......
Alabama	50	81.58	4.89	86.47	.23	.07	.17	.21	.12	3.81	2.70	.13	.05	4.04	7.07	......	......	......
Mississippi	97	85.87	4.39	90.26	.28	.11	.15	.31	.14	2.64	4.07	.09	.03	3.33	5.41	......	......	......
Louisiana	35	81.12	3.54	84.66	.19	.09	.16	.23	.02	3.12	4.24	.10	.05	4.26	6.66	......	......	......
Arkansas	38	....	......	88.54	.17	.06	.08	.43	.21	3.10	3.51	.15	.05	3.70	2.47	......	......	......
Kentucky	185	....	......	86.72	.20	.10	.08	.19	.20	6.01	3.52	.11	.04	3.69	1.85	......	......	.....
Ohio*	140	....	......	87 00	.26	.35	.28	.44	....	3.11	3.36	.11	.04	5.04	......	....	......	......
Oregon (W. of Cascades)	44	64.82	5.38	70.20	.23	.19	.83	.73	.09	11.64		.23	.16	3.20	......	1.55	......	......
Average for Humid Region	696	84.17	4.04	88.21	.21	.14	.13	.29	.13	3.88	3.66	.12	.05	4.40	......	1.22	......	......
" by States		81.59	3.45	85.04	.18	.11	.11	.26	.10	3.26	3.68	.12	.06	3.96	......	1.52	......	......
TRANSITION REGION.																		
Minnesota.*—Semi-humid	144	76.60	8.74	85.34	.30	.23	.65	.43	......	2.83	4.43	.22	.01	7.30	......	2.91	6.53	.19
North Dakota.*—Semi-arid	34	68.44	7.28	75.72	.42	.73	.91	.64	......	3.62	5.17	.19	.05	13.85	......	4.67	7.28	.34
Average for region	178	75.04	8.46	83.50	.33	.32	.70	.47	......	2.08	4.57	.21	.02	8.55	......	3.24	6.67	.22
ARID REGION.																		
Montana	59	70.98	4.17	75.15	.87	.27	1.03	1.36	.37	4.28	6.81	.22	.06	....	7.14	......	......	......
Idaho	17	75.34	5.22	80.56	.56	.26	.85	1.11	.02	3.85	6.38	.16	....	5.01	2.00	1.68	5.95	.10
Wyoming*	23	76.86	2.25	79.11	.64	.41	1.91	1.31	....	3.05	6.61	.18	.11	5.48	......	......	......	......
Colorado*	16	77.70	7.10	84.80	.44	.44	1.43	.81	....	3.82	4.98	.23	.08	3.57	2.31	......	......	.03
Utah*	38	....	......	81.04	.98	.53	1.77	.73	.03	3.08	5.50	.22	....	6.27	2.37	......	......	......
Arizona	20	64.58	13.78	78.36	.82	.43	2.37	1.89	.06	4.92	6.43	.13	.06	3.57	......	1.65	......	......
Nevada*	22	71.77	5.95	77.72	.54	.93	2.04	.96	.32	5.67	5.00	.32	.14	5.93	......	.....	......	.12
California	262	66.28	9.79	76.07	.61	.29	1.25	1.50	.06	6.61	8.44	.10	.06	4.74	6.09	0.91	15.23	.14
Oregon } East of	7	72.10	9.68	81 78	.54	.26	1.23	.73	.08	10.75		.11	tr.	4.40	......	.67	......	......
Washington } Cascades	109	71.60	6.09	77.69	.65	.36	1.25	.96	....	5.37	6.31	.21	.03	5.77	5.14	......	......	......
Averages for Arid Region	573	69.16	6.71	75.87	.67	.35	1.43	1.27	.11	5.48	7.21	.16	.06	5.15	5.46	1.13	12.50	.13
" by States	......	71.91	7.11	79.02	.67	.42	161	1.14	.13	4.74	6.27	.19	.07	4.71	5.34	1.03	10.59	1 0'

New Mexico.—Few analyses of New Mexico soils have been made, but the average results of six partial determinations made by Goss, and one full analysis made by Hare according to the method of the writer, and given below, show substantial accord with the averages of the above table. The averages of Goss' determinations are: Potash .780, Phosphoric acid .221, Nitrogen .108 per cent.

CHEMICAL ANALYSIS OF RIO GRANDE SILT (*by Prof. R. F. Hare.*)
Deposited on on land by irrigation.

Insoluble matter	63.70
Potash (K_2O)	1.06
Soda N_2aO)	.22
Lime (CaO)	4.97
Magnesia (MgO)	2.43
Br. ox. of Manganese (Mn_3O_4)	.14
Peroxid of Iron (Fe_2O_3)	5.80
Alumina (Al_2O_3)	6.86
Phosphoric acid (P_2O_5)	.16
Sulfuric acid (SO_3)	.13
Carbonic acid (CO_2)	7.45
Water and organic matter	9.98
Humus	1.17
" Nitrogen	11.11
" " per cent. in soil	.13
Hygroscopic Moisture	2.63
absorbed at ....°C	....

DISCUSSION OF THE TABLE.

Lime.—Considering in this table, first, *lime*, a glance at the columns for the two regions shows a surprising and evidently intrinsic and material difference, approximating in the average by totals to the proportion of 1 to 11; in the average by states, 1 to 14 ½. This difference is so great that no accidental errors in the selection or analysis of the soils can to any material degree weaken the overwhelming proof of the correctness of the inference drawn upon theoretical grounds, viz., that the soils of the arid regions must be richer in lime than those of the humid countries. For the differences in derivation would, in view of the wide prevalence of limestone formations in the humid regions concerned, produce exactly the reverse condition of things from that which is actually found to exist; and if further proof were needed it can readily be found in the detailed discussion of the analyses of the soils of the arid areas forming the contrast. This shows that for instance, in Washington highly calcareous soils are directly derived from the black basaltic rocks; while similarly, calcareous lands are found in California to be the outcome of the decomposition of granites, diorites, lavas, clay-shales and sandstones.

It is not easy to overrate the importance of this feature of the soils of the arid region, as it is intimately connected with other theoretically and practically important facts, in part already mentioned.

Summary of Effects of Lime Carbonate in Soils.—It is best to summarize, briefly, at this point, the advantages (and possible disadvantages), resulting from the presence of a proper amount of lime carbonate in soils, so far as these are at present understood.

Physically, even a small amount of lime carbonate, by its solubility in the carbonated soil-water, will act most beneficially in causing the flocculation of clay and in the subsequent conservation of the flocculent or tilth condition, by acting as a light cement holding the soil-crumbs together when the capillary water has evaporated; thus favoring the penetration of both water and air, and of the roots themselves. It should be added that according to the experience of the writer, amounts of lime carbonate in excess of 2% do not add to the favorable effects, except as would so much sand.

As to chemical effects, among the most important are:—

1. The maintenance of the neutrality of the soil, by the neutralization of acids formed by the decay of organic matter, or otherwise.

2. The maintenance, in connection with the proper degrees of moisture and warmth, of the conditions of abundant bacterial life (see above, chapter 9, p. 146); more especially those of nitrification, thus supplying the readily assimilable form of nitrogen. Also in favoring the development and activity of the root bacteria of legumes, and of the other nitrogen-gathering bacteria, such as Azotobacter (ibid. p. 156).

3. The rendering available, directly or indirectly, of relatively small percentages of plant-food, notably phosphoric acid and potash; as shown in the preceding pages.

4. The prompt conversion of vegetable matter into black,

neutral humus, and (as shown in the case of the soils of the arid region) the concentration of the nitrogen in the same; while accelerating the oxidation of the carbon and hydrogen, as shown by S. W. Johnson and others.

6. It counteracts the deleterious influence of an excess of magnesia in the soil, as first shown by Loew,[1] and verified by his pupils in Japan.

7. In alkali soils, according to Cameron and May, it counteracts the injurious action of the soluble salts upon the growth of plants, not only in the form of carbonate, but also in those of sulfate and chlorid.[2]

8. As a matter of experience, both in the case of grapes and orchard as well as wild fruits, an adequate but not excessive supply of lime in the soil will produce sweeter fruit than when lime is in small supply.

9. An excess of carbonate of lime in soils (from eight to twenty per cent and more), constituting "marliness," tends to seriously disturb the nutrition and general functions of many plants (calcifuge), and to produce a suppression or diminution of the formation of chlorophyll and starch; as in the case of grape vines, citrus fruits and others, which nevertheless flourish best in lands moderately calcareous.

Among the points thus enumerated the third and fourth require some comment. Without pretending to define exactly how lime acts in rendering other ingredients more available to plant assimilation, attention may be called to the fact that lime carbonate may be considered as acting similarly to, albeit more mildly than, caustic lime, in the displacement of other bases from their compounds. It doubtless acts thus in liberating potash from its zeolitic compounds. As to phosphoric acid, the connection of the effect of lime carbonate with the remarkable availability of that substance when present in the form of tetra-basic salt, in the case of phosphate slag, is at least possible.

As to the action of lime carbonate in forming humus,[3] no one who has observed the characteristic dark black tint of our calcareous

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[1] Bull. No. 1, Div. Veget. Physiol. and Plant Pathol. U. S. Dept. Agr.; et al.

[2] Loeb (Publications of the Spreckel's Physiological Laboratory of the University of California, has shown a similar protective influence of the lime salts in sea-water, against the other salts, in the case of the lower marine organisms.

[3] "Black Soils;" Agric. Science, January, 1892.

"prairie soils" can question the fact; which moreover is perfectly explicable upon the analogy already alluded to, with caustic lime, which, together with caustic alkalies (potash and soda), is known to act powerfully in the conversion of vegetable matter into humus. That instead of liberating the nitrogen in the form of ammonia, as do the caustic hydrates, the milder carbonate should only cause the formation of humic amides, is quite intelligible. That such is really the case, has been conclusively proved by the investigations of the writer made conjointly with M. E. Jaffa (Rep. Sta. Cal. Agr. Expt. 1892-4); the general result being that while in the humid region the average nitrogen-content of soil-humus is less than 5%, in the upland soils of the arid region (where *all* soils are calcareous) that percentage rises as high as 22.0%, with a general average of between 15 and 16%. That such highly nitrogenous material can be more readily attacked by the nitrifying bacteria than when a large excess of other oxidable matter is present, is at least a legitimate presumption, especially in view of the very active nitrification known to take place in the arid regions everywhere. So long as a large excess of carbohydrates is present, the oxidation of these will naturally take precedence over that of the relatively inert nitrogen. The accumulation of the latter in the humus-substance of the arid region, where oxidation of the organic matter of the soil is very active, points strongly to this view of the case.

Magnesia.—While the differences in respect to the proportions of lime are the most prominent and decided, yet the related substance, magnesia, shows also a very marked and constant difference as between the soils of the humid and arid regions. It will be observed that the general average for magnesia in the soils of the Atlantic Slope is about double that of lime; Florida and Rhode Island being the only states in which the average is lower for magnesia than for lime. In the arid region, on the contrary, magnesia on the general average is nearly the same as lime; in the average by states, somewhat less; thus bringing the ratio for the two regions for magnesia up to one to six or seven. This also is so decisive a showing that no accident could bring it about. We must conclude that climatic influences have dealt with magnesia similarly as with lime; which from the standpoint of the chemist is just what might be expected, since magnesia carbonate behaves very much like that of lime toward carbonated waters.

That magnesia is a very important plant-food ingredient is apparent from its invariable and rather abundant presence in the seeds of plants, where it takes precedence of lime. Its functions in plant nutrition have been specially investigated by O. Loew,[1] particularly with respect to its relations to lime. As already stated in connection with the soil-forming properties of magnesian minerals (see chapter 2), soils containing large proportions of magnesia generally are found to be unthrifty, the lands so constituted being frequently designated as " barrens." Loew finds that certain proportions of lime to magnesia must be preserved if production is to be satisfactory, the proportion varying with different plants, some of which (*e. g.* oats) will do well when the proportion of lime to magnesia is as 1 :1, while others require, that that ratio should be as 2 or 3 is to 1, to secure the best results. In general it is best that lime should exceed magnesia in amount.

Loew explains the injurious action of magnesium salts thus: The calcium nucleo-proteids of the organic structures are transformed in presence of soluble salts of magnesium into magnesium compounds, while the calcium of the former enters into combination with the acid of the magnesium salt. By this transformation the capacity for imbibition will change, which must result in a fatal disturbance of functions. The presence of soluble lime-salts will prevent that interchange. Thus certain algæ perished in a solution containing 1 per 1000 of magnesium nitrate, but remained alive when .3 per 1000 of calcium nitrate was added.

Magnesia seems to be specially concerned in the transfer of phosphoric acid through the plant tissues, in the form of dimagnesic-hydric phosphate, which is rather soluble in the acid juices of plants. It is probable that, apart from the relations just referred to, such excess of lime as is known to produce chlorosis in plants interferes with the transfer of the magnesic phosphate. Some plants, as already stated, dispose of an excess of lime by depositing it in the form of oxalate, while others (such as the stone crops) excrete it on the surface of

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[1] Bull. No. 18, Div. Vegetable Physiology and Plant Pathology; Bull. No. 1, Bureau of Plant Industry, U. S. Dept. of Agr.; Bull. College of Agriculture, Tokyo, Vol. 4, No. 5.

leaves and stems in the form of carbonate. But others seem to possess this power to a limited extent only.

In the case of soils containing much magnesia the proper proportion between it and lime may easily be disturbed by the greater ease with which lime carbonate is carried away by carbonated water into the subsoil, thus leaving the magnesia in undesirable excess in the surface soil. Hence the great advantage of having in a soil, from the outset, an ample proportion of lime. From this point of view alone, then, the analytical determination of lime and magnesia in soils is of high practical value.

Aso, Furuta and Katayama (Bull. Coll. Agr. Tokyo, Vol. 4 No. 5; Ibid. Vol. 6), have by direct experiment determined the most advantageous ratio of lime to magnesia in several crop plants. They find for rice and oats 1 : 1, for cabbage 2 : 1, for buckwheat 3 : 1; there being apparently a connection between the extent of leaf-surface and lime requirement, since leaves contain predominantly lime, while in the fruit, magnesia predominates.

Manganese.—A decided difference in the manganese content of the arid as against the humid soils appears in the table, the ratio being about 11 : 13 in favor of the humid soils. Manganese has not been regarded as being of special importance to plant growth in general, although, as already stated, some plants contain a relatively large proportion of manganese in their ashes; thus, *e. g.*, the leaves of the long-leaved pine of the cotton states.[1] But no definite data showing the importance of this element to crops were available until Loew and his co-workers at Tokyo[2] established its stimulating action in a number of cases, in which crop production was materially increased by the use of protoxid salts of manganese. Aso[3] applied manganous chlorid to an experimental plot of thirty square meters, at the rate of twenty-five kilos of Mn_3O_4 per acre, and thus obtained a yield of rice one-third greater than on the control plot, at a cost of about $2.00, while the value of the increase of the product was nearly $68.00. More experimental evidence on this subject is required to establish the *general* value

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[1] Rep. Agr. and Geology of Mississippi, 1860, p. 360.

[2] Bull. Agr. Coll. Tokyo, Vol. V., Nos. 2 and 4.

[3] Ibid. Vol. 6.

of the large-scale use of the salts of manganese; which are obtained in large quantities as a comparatively valueless by-product of the bleaching industries.

The "Insoluble Residue."

Remembering, in discussing the facts shown by the table, that the fundamental difference between the régime of the humid and arid regions is the presence in the latter of an almost continuous leaching process, in which the carbonated water of the soil is the solvent; remembering, also, that the least soluble portion of rocks and soils is quartz or silica (sand, as usually understood), it would be predicable that this ingredient should in the humid region be found to be more abundant in soils than in the arid. This portion is represented by the "insoluble residue" of the table.

Inspection shows that both in the averages of the single states, and in both of the general averages, this difference between the soils of the humid and the arid regions of the United States is strongly pronounced; the ratio being substantially as 69% in the arid region to 84% in the humid.

We must then conclude that the leaching process must have influenced materially other soil ingredients than lime, which have remained behind in such amounts as to depress the percentage of insoluble residue in the soils. It remains to be shown what are the substances so retained.

Insoluble and Soluble Silica and Alumina.

The ingredient most nearly correlated with the insoluble residue is the free silica which remains behind with it when the acid with which the soil has been treated is evaporated to dryness. The silica is separated from the practically insoluble, undecomposed minerals by boiling with a strong solution of sodic carbonate. The amount of this "soluble silica" is obviously the measure of the extent to which the soil-silicates have been decomposed in the treatment with acid.

The most prominent of these is usually supposed to be clay—the hydrous silicate of alumina that in its purest condition forms kaolinite or porcelain earth. Any alumina found in the usual course of soil analysis is generally referred to this mineral, which contains silica and alumina nearly in the proportion of 46% to 40%.

In very many cases, however, the reference of these two ingredients to clay is manifestly unjustified. This is clearly so when (as not unfrequently happens) the amount of alumina found exceeds that which would form clay with the ascertained percentage of soluble silica; it is almost as certainly so when, in addition to the alumina, other bases (notably potash, lime and magnesia), are found in proportions which preclude their being in combination with any other acidic compounds present. The only possible inference in such cases is that these bases, together with at least a portion of the alumina, are present in the form of hydrated, and therefore easily decomposable silicates or zeolites.

The subjoined analysis by R. H. Loughridge, of a clay obtained in the usual process of mechanical soil analysis (by precipitating with common salt the turbid water remaining after 24 hours subsidence in a column of 200 millimeters) from a very generalized soil of northern Mississippi, shows one of the many cases in which the numerical ratios of the several ingredients are incompatible with the assumption that silica and alumina are present in combination as clay (kaolinite) only:

ANALYSIS OF COLLOIDAL CLAY.

Insoluble matter	15.96
Soluble silica	33.10
Potash K_2O)	1.47
Soda (Na_2O)	1.70
Lime (CaO)	.09
Magnesia (MgO)	1.33
Br. ox. of Manganese (Mn_3O_4)	.30
Peroxid of iron (Fe_2O_3	18.76
Alumina (Al_2O_3)	18.19
Phosphoric acid (P_2O_5)	.18
Sulfuric acid (SO_3)	.06
Carbonic acid (CO_2)	.00
Water and organic matter	9.00
Total	100.14

If in this case we assign all alumina to silica, as required for the composition of kaolinite or pure clay, there yet remains a trifle over twelve (12.17) per cent of silica to be allotted to the other bases present. Deducting from this the ascertained amount of silica soluble in sodic carbonate, pre-existing in the raw material (.38 per cent), we come to 11.79 per cent. as the amount of silica which must have been in combinations other than kaolinite, viz., hydrous silicates, or soil zeolites, formed either with the bases other than alumina shown in the analysis or, more probably, containing some of the alumina itself in essential combination.

We are thus enabled to obtain from the determination of the soluble silica an estimate of the extent to which these soil zeolites, that form so important a portion of the soil in being the repositories of the reserve of more or less available mineral plant-food, are present in the soils of the several regions. A glance at the table shows that the general average of soluble silica is very much greater in the soils of the arid regions than in those of the humid, approximating one to two in favor of the arid division.[1]

Differences in the Sands of the Arid and Humid Regions.—In chapter 5 mention has been made of the fact that while in the humid regions, "sand" as a rule means quartz grains, mostly with a clean surface and very frequently rounded and polished, in the arid regions even the coarse sand grains consist of, or are covered with, a great variety of minerals in a partially decomposed condition. This is owing to the absence of the abundant rainfall which in humid climates continually washes down the finely divided, half-decomposed mineral matter into the subsoil; while in arid climates the light rains cannot produce any such washing effect and hence the sand grains remain incrusted with the products of either their own decomposition, or of that of neighboring particles; it being therefore not concentrated in the finer portion only, viz., the clay and finest silts. This fundamental difference, which is illustrated in the analytical table below, at once explains why in the arid regions generally, sandy soils are found so highly productive that, owing to their easy cultivation they are preferred to the clayey lands, in which tillage and irrigation are more difficult.

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[1] Looking at the details of the several states, we find that on the arid side Washington has a relatively low figure for soluble silica, which in the average, however, is overborne by the high figures for California and Montana. The explanation of this fact probably lies in the derivation of the majority of the Washington soils examined, from lake deposits brought down gradually from the humid region at the heads of the Columbia drainage, where sandy beds are very prevalent; while the country rock—the basaltic eruptives—are very basic, and moreover slow to disintegrate. In California and Montana the rocks are infinitely varied, and the general outcome of their weathering is plainly a predominance of complex hydrous silicates in the soils, as compared with humid regions.

It is a well-known fact that on the "sands of the desert" when either irrigated, or wetted by rain, vegetation at once springs up with remarkable luxuriance, even on sand drifts; and this productiveness appears to be quite as lasting as that of "strong" clay soils of the humid regions.

This difference is curiously illustrated on the southern edge of the "black adobe" or prairie soil area which surrounds Stockton, Cal. Here we find on the opposite sides of a small stream (French Camp slough) the two extremes, of heavy clay and the sandy soils which for many years made Stanislaus county the "banner" county for wheat. The grain product of both banks ranked alike in quantity and quality in average years; but in extreme seasons sometimes one, sometimes the other failed, according to the weather conditions which favored one or the other soil. No one would think of sowing wheat on so sandy a soil in the humid States.

TABLE ILLUSTRATING DIFFERENCE IN SANDS OF THE HUMID AND ARID REGIONS.

Clay.	Per cent in Soil.	Potash.	Lime.	Magnesia.	Phosphoric Acid.	Soluble Silica.	Alumina.	Summation.
Mississippi[1]	21.64	.32	.03	.29	.04	7.17	3.97	11.82
California 1281 Chino[2]	7.60	.16	.14	.17	.04	1.70	1.35	3.56
do. Jackson[3]	16.43	.13	.12	.08	.05	2.83	2.13	5.34
Silt .06—.016mm. diam								
Mississippi	35.10	.41	.15	.36	.07	2.87	1.36	5.22
California (Chino)	18.53	.24	.53	.29	.06	4.96	1.76	7.84
" Jackson	34.90	.10	.04	.08	.02	2.50	2.44	5.18
Silt .016—.025 mm. diam								
Mississippi	13.67	.12	.09	.10	.02	.32	.17	.82
California, Chino	5.49	.05	.11	.02	.01	.80	.51	1.50
" Jackson	9.96	.08	.04	.10	.007	1.01	1.01	2.25
Silt .025—.036 mm. diam								
Mississippi								.36
California, Chino	3.92							lost
" Jackson	7.68	.06	.02	.05	.006	0.82	.74	1.70
Silt .036—.047 mm. diam								
Mississippi							.55	trace
California, Chino	6.40	.05	.18	.07	.01	.80	.64	1.66
" Jackson	8.21	.04	.01	.003	.001	.43		1.12
Coarse Silt 047—.072 mm. diam								
California, Chino	7.92	.06	.23	.03	.02	.89	.59	1.79
" Jackson	5.91	.01	.01	.013	.003	.42	.30	.77
Fine sand .072—.12 mm. diam.								
California, Chino	11.87	.06	.26	.10	.03	.98		1.43
" Jackson	4.03	.01	.01	.005	.003	.28	.09	.40
Sand .12—.50 mm. diam								
California, Chino	36.11	.11	.69	.12	.04	2.43	1.59	4.98
" Jackson	10.10							Not detd.

It thus appears that while in the Mississippi soil, solubility of plant-food practically ceased at grain-diameter of .036 mm, in

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[1] Analyses by R. H. Loughridge. [2] Analyses by L. M. Tolman. [3] Analyses by E. H. Lea.

the arid California soils, as large an amount was found in the sand-grain sizes between .12 and .50 millimeters as in the fine silt .016 to .025 mm. in Mississippi.

Hydrous Silicates are More Abundant in Arid than Humid Soils.—This predominance of hydrous silicates in the soils of the arid regions should not be a matter of surprise when we consider the agencies which are brought to bear upon these soils with so much greater intensity than can be the case where the solutions resulting from the weathering process are continually removed as fast as formed, by the continuous leaching effect of atmospheric waters. In the soils of regions where summer rains are insignificant or wanting, these solutions not only remain, but are concentrated by evaporation to a point that, in the nature of the case, can never be reached in humid climates. Prominent among these soluble ingredients are the silicates and carbonates of the two alkalies, potash and soda. The former, when filtered through a soil containing the carbonates of lime and magnesia, will soon be transformed into complex silicates, in which potash takes precedence of soda, and which, existing in a very finely divided (at the outset in a gelatinous) condition, serve as an ever-ready reservoir to catch and store the lingering alkalies as they are set free from the rocks, whether in the form of soluble silicates or carbonates. The latter have another important effect: in the concentrated form at least, they, themselves, are effective in decomposing silicate minerals refractory to milder agencies, such as calcic carbonate solution; and thus the more decomposed state in which we find the soil minerals of the arid regions is intelligible on that ground alone.

It must not be forgotten that lime carbonate, though less effective than the corresponding alkali solutions, nevertheless is also known to produce, by long-continued action, chemical effects similar to those that are more quickly and energetically brought about by the action of caustic lime. In fact, the agricultural effects of "liming" are only in degree different from those produced by marling with finely pulverized carbonate; and in nature the same relation is strikingly exemplified in the peculiarly black humus that is characteristic of calcareous lands, but which can be much more quickly formed under the influence of caustic lime on peaty soils.

In the analysis of silicates we employ caustic lime for the setting-free of the alkalies and the formation of easily decomposable silicates, by igniting the mixture; but the carbonate will slowly produce a similar change, both in the laboratory and in the soils in which it is constantly present. This is strikingly seen when we contrast the analyses of calcareous clay soils of the humid region with the corresponding non-calcareous ones of the same. In the former the proportions of dissolved silica and alumina are almost invariably much greater than in the latter, so far as such comparisons are practicable without assured absolute identity of materials. That is, calcareous clays or clay soils are so sure to yield to the analyst large precipitates of alumina, that experience teaches him to employ smaller amounts for analysis than he would of non-calcareous materials, in order to avoid unmanageably large bulks of aluminic hydrate. It is but rarely that even the heaviest non-calcareous soils yield to the acid usually used in soil analysis more than 10 per cent. of alumina; while heavy calcareous clay (prairie) soils commonly yield between 13 and 20 per cent.[1] It would be interesting to verify this relation by artificial digestions of one and the same clays with calcic carbonate at high temperatures, as it must always be extremely difficult to insure absolute identity of all other conditions in natural materials.

In most of these cases, what is true of alumina is also true of the soluble silica. But since the latter is constantly liable to be dissolved out by solutions of carbonated alkalies, it is not surprising that this relation is not always shown.

Aluminic Hydrate.—In numerous cases, the amount of alumina dissolved in analysis is greatly in excess of the soluble silica, so as to force the conclusion that a portion of the latter must be present in a different form from that of clay (kaolinite); the only choice being between that of complex hydrous silicates (none of which, however, could contain as large a percentage of alumina as clay itself) and *aluminic hydrate.* The latter is alone capable of explaining the presence of more alumina than silica in easily soluble form;[2] and the visible occurrence of "gibbsite" and "bauxite" in modern forma-

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[1] Report of the Tenth Census, Vols. 5 & 6; see especially the analyses of soils from Mississippi and Alabama. Also the Reports of the California Experiment Station.

[2] Excepting the relatively rare minerals of the Allophane, Kollyrite, and Miloshite group.

tions renders this a perfectly simple and acceptable explanation. Since these minerals are known to be incapable of crystallization, we are moreover led to the presumption that it will as a rule be found in the finest portions of the soil, viz., in the "clay" of mechanical analysis.

Some illustrations of these conditions are given below, for soils from Mississippi and California. The soluble silica being all assigned to kaolinite, the rest of the alumina must be assumed to be present as hydrate, since no other compound could fulfil the stoichiometrical requirements.[1] The table therefore shows the differences between the amounts of alumina found by analysis, and those assignable to kaolinite, calculated to the mineral bauxite—the most abundant, as well as the one containing the medium proportion of water, among the three naturally occurring aluminic hydrates.

TABLE SHOWING EXCESS OF ALUMINA OVER SILICA IN SOILS; CALCULATED AS BAUXITE.

Number.	Name of Soil.	County.	State.	Total soluble in HCl.	SiO_2	Al_2O_3.	Corresponding to Bauxite.	Other Solu. Matters.
195	Prairie................	Alcorn...	Mississippi.	28.57	3.6	14.4	14.12	2.92
346	Dark Loam..........	Chicasaw	"	10.32	6.6	11.2	6.91	.86
288	Flatwoods Clay......	Pontotoc.	"	26.94	5.0	11.3	8.75	3.48
676	Red Volcanic.........	Lake	California.	41.00	5.9	22.6	21.90	2.00
332	Mojave Desert.......	Kern ...	"	24.82	5.0	9.2	6.10	5.13
191	Red Foothill.........	Merced...	"	23.32	4.5	8.8	6.20	3.05
705	Red Chaparral........	Shasta....	"	28.75	5.5	14.4	12.10	1.12
706	" " Subsoil..	"	"	28.40	4.7	17.4	16.70	1.32
573	Tulare Plains........	Tulare....	"	29.27	3.4	8.7	7.20	11.16
701	Dry Bog.............	"	"	27.29	4.3	12.4	10.90	5.04
1004	"Slickens" Sed.......	Butte....	"	30.80	8.0	14.2	9.20	1.95
656	" "	Yuba	"	22.23	3.0	10.4	9.80	2.19
517	Brownish Loam.	Butte	"	29.80	4.8	12.0	9.80	4.42
561	Black Loam..........	"	"	30.21	3.2	13.0	12 80	4.67
563	Sacramento Alluvium.	"	"	23.46	2.7	10.4	10.90	4.58
863	Red Foothill.........	Nevada ..	"	56.80	11.0	36.4	33.60	1.22
861	" "	"	"	45.46	11.5	22.0	14.10	3.97

It is apparent from this table that if, as is probable, the aluminic hydrate accumulates in the "clay" of the analysis, it will in some cases form a very considerable percentage of the same, and detract to that extent from its plastic, adhesive and other properties. But it must be remembered that the assumption upon which this table is calculated, leaves out of consideration the zeolitic portion, which as the 6th column shows, is frequently quite large as measured by the bases found, to

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[1] Since any complex zeolite would contain *less* alumina than kaolinite, this assumption more than covers the possible zeolitic alumina.

which no other form of combination can be assigned. Since some of the alumina undoubtedly takes part in the formation of such zeolites, the silica must to that extent be withdrawn from the estimate made for kaolinite. While it is impossible to make any definite numerical allowance for this fact, it clearly will tend in many cases to increase materially the amount of alumina that must be assigned to the hydrate condition. It will be noted that in most cases given, the alumina per cent is rather large.

The relatively large number of such cases shown in the table for California soils is not a matter of accident; for even a cursory glance at the columns of analyses of California (and Washington and Montana) soils, shows that the cases in which the alumina exceeds the silica in amount are rather predominant, while the reverse is the case in the humid region.[1] But it must not be inferred that the reverse relation is not also frequently observed even in the arid region; it occurs in fact in close proximity to the localities where some of the most striking instances of excess of alumina over soluble silica have been found.

Thus Nos. 861 and 863 from the neighborhood of Grass Valley, which show this excess most strikingly, occur within 15 miles of localities which show almost the reversal of the numbers given for the two former, and at a level of about a thousand feet lower. It would seem, on the whole, that the excess of alumina occurs most frequently in connection with soils formed from eruptive rocks; in the case referred to, from volcanic ash. It will require more detailed study to detect the causes of these marked differences.

Retention of Soluble Silica in Alkali Soils.—It is somewhat surprising that, contrary to the expectation one would naturally entertain, the alkali lands, so frequently rich in the carbonates of the alkalies that would dissolve free silica, on the contrary, show most frequently an excess of soluble silica over alumina. This is probably to be explained from the very liberal opportunities afforded in the alkali soils for the formation of complex zeolitic masses by the retention in soil of the soluble alkali salts, and the abundance of lime always present in them. As already stated, we usually find in alkali soils a very large proportion

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[1] See for comparison the data given in vols. 5 and 6 of the report of the Tenth Census of the United States.

of both alkaline and earthy bases in acid-soluble silicate combinations. But much farther research is needed to explain fully the marked discrepancies observed in this respect between soils not only occurring in closely contiguous localities, but also showing marked similarities in their general composition.

Ferric Hydrate.—There is no obvious reason, from the chemical standpoint, why iron, that is, ferric hydrate or iron rust, should be more abundant in the soils of the arid regions, as the averages given in the table suggest; moreover, the fact does not impress itself upon the eye, since the orange or reddish tints are by far more common in the humid than in the arid regions of the United States at least. The California average is considerably influenced by the very highly ferruginous soils from the foothills of the Sierra Nevada, and by the black (magnetite) sand so commonly present; that of Oregon by the black, highly ferruginous country rock (basalts), from which they are partly derived. The average for Montana is not higher than that of three states of the humid region, and less than that of Kentucky. We might imagine a cause for depletion of iron in the soils of the humid areas in the frequency with which humid moisture and high temperature will during the summers concur toward the bringing about of a reducing process in the soil, which by getting the iron into proto-carbonate solution would make it liable to be leached into the subsoil, as is frequently the case; yet the resulting "black gravel" or bog ore, in its various forms, is of not infrequent occurrence in the arid regions also. A constant quantitative difference due to climatic conditions does not appear to be shown by the data thus far at command, but the *finer distribution* of the ferric hydrate in the humid temperate as well tropical regions is obvious to the observer, from the frequent redness of humid and tropical soils.

Manganese.—An unexpected and apparently well-defined contrary relation appears to be shown as regards the related metal *manganese;* the average percentage of which is in all cases less in the arid than in the humid region. The cause of this relation is altogether obscure; it is too frequent to be accidental.

Phosphoric Acid.—As regards that highly important soil ingredient, *phosphoric acid,* the indication in the table that there is no characteristic difference in the average contents in soils of the arid and humid regions, respectively, is doubtless correct. This substance is so tenaciously retained by all soils that there is no obvious reason why there should be any material influence exerted upon its quantity by leaching, or by any of the differences in the process of weathering that are known to exist between the two climatic regions. Moreover, it is apparent that the average for the arid region is made up out of very widely divergent figures; that of California exceptionally low (lower than any of those for the states of the humid regions), while those for Washington and Montana are exceptionally high. The latter is due to country rocks ("basalts") showing abundance of microscopic crystals of apatite, which in some cases raise the contents of the soils in phosphoric acid to nearly twice the average given for the states.

The forecast that for most California soils, fertilization with phosphates is of exceptional importance, has already been abundantly confirmed by cultural experience. Few definite data are as yet available from other arid states, where fertilization is thus far sporadic and unsystematic. But it is predicable that in view of the presence of an excess of lime carbonate in the arid soils, and the unfavorable effect of this compound on the *rapid* solubility of tricalcic phosphate demonstrated by Schloesing, Jr.,[1] by Böttcher and Kellner[2] and Nagaoka,[3] fertilization with readily available phosphate fertilizers will be found necessary among the first, all over the arid region, especially in view of the scarcity of humus in arid soils.

A curious instance of the effects of continued warm maceration in rock decomposition is afforded by the highly ferruginous soils derived from the black basaltic lavas of the Hawaii Islands. These lavas, like the basalt sheet of the Pacific Northwest, contain a large amount of crystallized phosphate minerals, notably apatite and vivianite. A correspondingly large proportion of phosphoric acid is found in the soils

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[1] Ann. Sci. Agronomique, tome 1, 1899.

[2] Landw. Presse, 1900, No. 52; ibid. 1901, Nos. 23 and 24.

[3] Bull. Univ. Tokyo, Vol. 6, No. 3. Production was diminished to less than one half when lime was used with bone meal, and actual assimilation of phosphoric acid to one fifth.

derived from these rocks, up to nearly two per cent.[1] But almost the entirety if this substance is present in the form of an insoluble, basic iron compound, difficultly soluble even in acids, and rendering it wholly unavailable to vegetation. So that actually the most pressing need of most of these soils is phosphate fertilization. The same is probably true of some of the highly ferruginous soils of California and of the Cotton States.

Sulfuric Acid.—From the absence of the leaching process in the soils of the arid region, we should expect that sulfates would be more abundant in them than in the soils of the humid. This is certainly true in the case of the alkali soils, which are characteristic of the regions of deficient rainfall. See below, chapter 22.

Hence the showing made in the general table, indicating that sulfates are equally abundant in the soils of the humid than in those of the arid regions, is surprising in view of the efflorescences of alkali sulfates so frequently observed in the latter. This is obviously due to the fact that the majority of such alkali soils has, on account of their local nature and usually heavy lime content, been excluded from the comparison; which otherwise would have made a very different showing.

Potash and Soda.—The compounds of the alkali metals potassium and sodium, being on the whole much more soluble in water, even without the concurrence of carbonic acid, than those of calcium and magnesium, the leaching process that creates such pronounced differences in the case of the two earths must affect the alkali compounds very materially. Comparison of the soils of the two regions in this respect shows, indeed, very great differences in the average contents of potash and soda. For potash the ratio is .216 to .670 per cent. on the general average, and .187 to .670 per cent., in the average by states; for soda, .140 per cent. to .350 per cent. on the general average, and .110 per cent. to .420 per cent. in the average by states. For both, therefore, the general average ratio is as one to between three and four for the humid as against the arid region.

It is curious that an approximation to the ratio of one to

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[1] See table, chapter 19, p. 256.

two, or somewhat less, is maintained in the average proportion of soda to potash in both regions; but this does not by any means hold good in detail, very high potash-percentages being often accompanied by figures for soda very much below the above ratio. This is the result of an important difference in the chemical behavior of the two alkalies, which has already been alluded to in connection with the discussion of the zeolites. (See chapter 3, p. 38).

The process of "*kaolinization,*" being that by which clays are formed out of feldspathic minerals and rocks such as granite, syenite, trachyte, etc., results in the simultaneous formation of solutions of carbonates and silicates of potash and soda. These coming in contact with the corresponding compounds of lime and magnesia, also common products of rock decomposition, are partly taken up by the latter, forming complex, insoluble, hydrous silicates (zeolites). In these, however, potash whenever present takes precedence of soda; so that when a solution of a potash compound is brought in contact with a zeolite containing much soda, the latter is partially or wholly displaced and, being soluble, tends to be washed away by the rainfall into the country drainage. Hence potash, fortunately for agriculture, is tenaciously held by soils, while soda accumulates only where the rainfall or drainage is insufficient to effect proper leaching, and in that case manifests itself in the formation of what is popularly known as "alkali soils;" namely those in which a notable amount of soluble salts exists, and is kept in circulation by the alternation of rainfall and evaporation, the latter causing the salts to accumulate at the surface and to manifest themselves in the form of saline crusts or efflorescenses. Alkali lands are a characteristic feature of all regions of scanty rainfall, and are found more or less on all the continents. The substances composing the alkali salts are retained not only in their soluble form, but by their continued presence influence profoundly, in several ways, the processes of soil formation. A more detailed discussion of this important subject is given in chapters 22 and 23.

Arid Soils are Rich in Potash.—One of the most important practical conclusions flowing from the comparison of the potash contents of the humid and arid soils respectively is that while in the former, potash is usually among the *first* substances to be supplied by fertilization when production languishes, in the arid regions it will as rule come *last* in order among the three ingredients commonly so furnished. Aside from the water-soluble potash salts always forming part of the salts of the alkali lands proper, which in many cases will alone hold out for many years under the demands of cultivation,[1] they rarely contain much less than one per cent. of acid-soluble potash; occasionally rising as high as 1.8 per cent. That in such lands potash-fertilization is uncalled-for and ineffective, hardly requires discussion; while on the other hand, phosphates are commonly required for full production after ten or fifteen years of cultivation without returns. Nitrogen usually comes next in order, but sometimes is the first need.

The constant indiscriminate purchase and use of all three ingredients, so urgently recommended by fertilizer manufacturers because of their success in the humid Eastern States, is therefore very poor economy for the farmers of the arid region. Excepting cases of very intense culture, *e.g.* of vegetables or berries, the use of potash salts is but rarely remunerative, and therefore uncalled-for, in arid soils for a number of years.

Humus.—The figures shown in the table for the average humus-percentages in the soils of the two regions do not adequately represent the very important differences actually existing; partly because of the inadequate number of determinations made by the same method (Grandeau's), partly because of the differences in the composition, and especially in the nitrogen-content of this substance, which render direct comparison delusive. A detailed discussion of the marked differences existing between the humus of arid and humid soils in this respect has already been given (chapter 8, p. 135); showing that the high nitrogen-percentage in the arid humus probably compensates largely the lower humus-percentage, while rendering nitrification more rapid, because the oxygen is not consumed by overwhelming amounts of carbon and hydrogen; which, as is already known, take precedence of nitrogen in the oxidation of humus substances. Nitrates are almost always

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[1] In the light alkali lands of the southern California Experiment Substation at Chino, the average content of water-soluble potash in ten acres amounts to the equivalent of 1,200 pounds of potash sulphate per acre. Outside of this the acid-soluble potash of the soil is .95°/₀, equal to 38,000 pounds per acre-foot.

more abundant in the soils of the arid region than in those of the humid, sometimes to the extent of influencing injuriously the quality of certain crops, such as tobacco and sugar beets. Nevertheless, nitrogen is ordinarily, in the arid region, the substance requiring replacement next to phosphoric acid. And when considered in connection with the small humus-content, so liable to burning-out, this places *green-manuring with leguminous plants* among the first and most vital improvements to be employed there.

The Transition (semi-humid or semi-arid) Region.—The sloping plains country lying between the Rocky Mountains and the Mississippi, quite arid at the foot of the mountains, but with rainfall increasing more or less regularly to eastward, form a transition-belt between the arid and humid region of which but a small portion has been systematically studied in respect to its soil formations. The analyses made of soils of the two adjacent states of Minnesota and North Dakota, have been placed in the general table (p. 377) to show how far in their general relations their soils correspond to the generalizations deduced from the comparison of the decidedly arid and humid soil areas chiefly represented in the table. Although it has not been possible, for lack of detailed data, to eliminate the soils originating from calcareous formations, it will be seen that those of semi-arid Dakota differ from those of more humid Minnesota, almost throughout, as would be anticipated from the studies of the extremes, given in this chapter.

CHAPTER XXI.

SOILS OF ARID AND HUMID REGIONS (*Continued*).

SOILS OF THE TROPICS.

WITHIN the ordinary limits of atmospheric temperatures, and in the presence of adequate moisture, chemical processes active in soil-formation are intensified by high and retarded by low temperatures, all other conditions being equal. We can usually artificially imitate, and produce in a short time by the application of relatively high temperatures, most of the chemical changes that naturally occur in soil-formation. While it is true that the changes of temperature are nearly as great in the tropical as in the temperate climates, these changes all occur at a higher level and within the limits favoring bacterial and fungous action.

This being true we should expect that the soils of tropical regions should, broadly speaking, be more highly decomposed than those of the temperate and frigid zones, and that the intensified processes continue currently. This fact has not been as fully verified as might be desirable, by the direct comparative chemical examination of corresponding soils from the several regions, owing to the want of uniformity in methods and the fewness of such investigations in tropical countries. Yet the incomparable luxuriance of the natural as well as artificial vegetation in the tropics, and the long duration of productiveness that favors so greatly the proverbial easy-going ways and slothfulness of the population of tropical countries, offers at least presumptive evidence of the practical correctness of this induction.

In other words, the fallowing action, which in temperate regions takes place with comparative slowness, necessitating the early use of fertilizers on an extensive scale, is much more rapid and effective in the hot climates of the equatorial rainy belt; thus rendering currently available so large a proportion of the soil's intrinsic stores of plant-food, that the need of artificial fertilization is there largely restricted to those soils of which the parent rocks were exceptionally deficient in the mineral ingredients of special importance to plants, that ordinarily form the essential material of fertilizers. Quartzose, magnesian, and other soils resulting from the decomposition of "simple" rocks will, of necessity, be poor in plant-food everywhere.

Humus in Tropical soils.—Another inference from the climatic conditions of the tropics is that the *properly* tropical soils are likely to be rich in humus, as a result of the luxuriant vegetation which in the decay of its remnants must leave abundant humic residues. This seems to be generally verified wherever the interval between rainy seasons is not too long; for otherwise, under the great and constant heat of the tropics a rapid burning-out of the humus, such as is known to occur in the arid regions, must also take place. A good example illustrating the intertropical regime as regards humus is given in the table in chapt. 8, p. 137, showing the humus-content of some Hawaiian soils. Both are of the same order as in the soils of the temperate humid region, though the nitrogen-content evidently can, consistently with productiveness, range lower than has thus far been observed in temperate climates. This again forms a striking contrast with the soils of the arid regions.

It is greatly to be regretted that not even approximate determinations of the organic matter, much less of the humus-substance proper, have been made by any of those who have analyzed tropical soils; excepting those made of Hawaiian soils at the California Experiment Station.

The "loss by ignition" is of course always very largely ially water, mostly ~~referrible~~ to ferric hydrate and clay substance, the latter presumably essentially in the form of kaolinite. When, therefore, ferric oxid and alumina have been determined, we may approximate to the amount of total organic matter by making allowance for ferric hydrate at the rate of about 14% of the ferric oxid, for kaolinite at that of 34.92% of the alumina found. Deducting these amounts of water from the total "loss by ignition," we may obtain at least an approximate idea of the organic matter, and the probable availability of the nitrogen determined by the analysis. See chapter 19, p. 357.

While the continuous heat and moisture of the tropics concur toward rapid rock-decomposition, it must be remembered that the copious rainfall is equally conducive to an *intense leaching effect.* Striking examples of this action occur in the Hawaiian Islands, in the highly ferruginous soils resulting from the decomposition of the black (pyroxenic and hornblendic) lavas that are so characteristic of the volcanic effusions of that region. The soils formed from these rocks are sometimes so rich in ferric hydrate (iron rust) that they might well serve as iron ores elsewhere. But these soils are very unretentive, and though very productive at first they are soon exhausted, the abundant rains having sometimes deprived them of almost every vestige of lime, and of most of the potash contained in the original rock. At the same time the abundant phosphoric acid of the original rock has been reduced to almost total unavailability by combination with ferric oxid, just as in the case of the bog ore of the temperate climates; so that phosphate fertilization is urgently needed in these lands, though showing high percentage of phosphoric acid. (Chapt. 19, p. 356.)

Soils highly colored by ferric hydrate occur rather frequently in the tropics, and have received the general name of "laterite" soils. Curiously enough, the intense reddish tint mostly shown in these soils, and which is emphasized in the "terra roxa" of the Brazilians, and the general "red" aspect of Madagascar, and of the Malabar and Bengal coasts, is by no means always accompanied by markedly high percentages of iron oxid; but the latter is very finely diffused, so as to be very effective in coloration. The plant-food percentages of tropical soils are generally quite low, so that in the temperate humid regions such lands would be adjudged to be rather poor. Yet they mostly prove quite productive and lasting, even without fertilization.

This is doubtless to be explained by the continuous and rapid rock and soil-decomposition which goes on under tropical climatic conditions, already alluded to; so as to supply enough available plant-food for the demands of each season's vegetation, analogously to the proverbial "nimble penny." This is supplemented also by the rapid decay and leaching-out of the ash ingredients of the rapidly decaying and dying vegetation. Nitrification must likewise, of course, be very active under the continual heat and moisture, and the humus formed under these circumstances is likely to be quite poor in nitrogen. On this latter point, however, definite data are almost wholly wanting.

Investigations of Tropical Soils.—The most extended chemical investigations of properly tropical soils have been made by Wohltmann in his investigations of the soils of India, German Southwest and Southeast Africa, and Samoa;[1] and by Müntz and Rousseaux of soils collected under Government auspices in Madagascar. Leather, Bamber and Mann have also analyzed a large number of soils of India. But we find in many of these cases a failure to specify distinctly the local climatic conditions, and even the depth to which the samples have been taken; so that the investigator is obliged to examine laboriously the local climates, and especially the amount and distribution of rainfall, before being enabled to discuss intelligently the data given. Even Wohltmann, in his discussion of North African and Saharan soils, classes these distinctly arid types among the tropical ones.

Again, the dry seasons intervening between the tropical rains, varying in length and from locality to locality, obscure somewhat the relations of the soils to the climatic conditions. Under the lee of mountains, even of slight altitude, we find xerophytic (arid-land)vegetation, as has been noted by many observers in Brazil, even near the Amazon; in Hawaii, in Jamaica, and in Madagascar. Unless, therefore, a close discrimination is exercised by field observers, many contradictory results will appear in analyses of soils of inter-tropical countries. This is naturally the case in India, where the topographic surface conformation and seasonal climatic conditions are so complicated and contrasted. On the whole, the results obtained in Samoa, Kamerun and Madagascar seem, of those available, to be the most characteristic of true tropical conditions. In comparing these with the soils of low plant-food percentages in the temperate humid region (see chapter 19, p. 352), it must be remembered that those mentioned as being productive are so by virtue of great depth and relatively high

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[1] Samoa Erkundung, by F. Wohltmann, Kolonial-Wirthsch, Komitee, Berlin, 1904.

proportions of lime; while in the tropics, the intense leaching process prevents lime from reaching any high absolute or relative percentages, save where limestone formations prevail. Moreover, the mode of preparation of the soil extracts for analysis by Wohltmann, and by Müntz and Rousseaux, differ so widely from that forming the basis of discussion of soil-composition in this volume, that it becomes necessary to make separate allowances in each case; since some of the ingredients, phosphoric acid, lime and magnesia, are fully dissolved by the weaker treatments, while others,—*e. g.*, potash—are not, and are therefore not directly comparable with the data obtained in the writer's work. The analyses made in India by Leather and others have apparently been made substantially in accordance with the author's methods and may be considered directly comparable.

SOILS OF SAMOA AND KAMERUN.

Wohltmann has investigated the soils of Samoa, notably those of the main island of Upolu, under the auspices of the German "Kolonial-Wirthschaftliche Komitee" in 1903, and gives the results of his observations and analyses in a report published at Berlin in 1904. The analyses are quite numerous, but unfortunately are made by a special method which renders them only partly comparable with those of any other analyst.

Wohltmann's method is this: "450 grams of fine earth (below 2 millimeters diameter) is treated for 48 hours with 1½ liters of cold chlorhydric acid of 1.15 density. Another portion, designed for a fuller determination of potash, is treated for one hour with the same acid, boiling hot. Potash was determined in both soil extracts; the hot extract gave from one-third to twice the amount obtained in the cold extraction."[1]

Wohltmann justifies this method by the statement that it has yielded him results more nearly in accord with experience than any other tried, both with tropical and European soils.

Under these conditions only a few of the determinations in Wohltmann's analyses are directly comparable with those upon which the discus-

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[1] Wohltmann states that the hot extraction sometimes yielded as much as five times more than the cold; but no such case appears in his reports on Samoa and Kamerun.

sions in this volume have been based. The figures for nitrogen and phosphoric acid may be assumed to be fully comparable; that of lime will in general represent fully only that which is present in the forms of carbonate, sulfate and humate, and a part of that existing in zeolitic or hydrous silicate form. Of the two potash determinations only the one made in hot extraction will be even remotely comparable, being probably at least 30% lower than would have been obtained by the writer's method.

Even thus, however, Wohltmann's results are highly instructive. He gives the following summary of his mode of interpreting such analyses:

	Very rich.	Good.	Inadequate.
Potash	.2	.1	.05
Lime and Magnesia	1.0	.4	.07
Phosphoric acid	.2	.1	.06
Nitrogen	.2	.1	.05

It will be observed that the figures of this table differ materially only in the matter of potash from those given in chapter 19, p. 354; for the latter substance they would have to be multiplied by from 2 to 4, according to the lime-content and other conditions.

With this understanding a number of Wohltmann's analyses of soils from Samoa and Kamerun are given below, the potash determinations made with hot acid being placed in parentheses after the other.

Soils of Samoan Islands.—A discussion of these analyses shows, from the writer's point of view, a very low content of potash and lime, with the peculiarity that both are somewhat higher at the depth of a meter than in the surface ten-inches. This is probably to be accounted for from the very high content of organic matter (humus), which is apparent from the high "loss by ignition," a very large proportion of which must be credited to the burning of the organic matter. That this humus reaches to the lowest depths examined, is clear from the nitrogen-content given for these samples. Wohltmann, whose estimate of these soils agrees in most respects with the writer's, attributed to them a very satisfactory nitrogen-content. This would be true of the total; but as

ANALYSES OF TROPICAL SOILS BY F. WOHLTMANN.

EXTRACTION WITH COLD CHLORHYDRIC ACID, SP. G. 1.15, for 48 HOURS.

	SAMOAN ISLANDS.					KAMERUN.			
	Upolu.			Savaii.		Isongo.		Mundame II.	
	Tuanaimato. Virgin Forest Soil,	Le Utu Sao Vaa Cultivated Soil.		Cleared Land.					
Depth.	not given.	0.—25 cm. (10 ins.)	75—100 cm. (30—40 ins.)	0—25 cm. (0—10 ins.)	75—100 cm. (30—40 ins.)	0—25 cm. (10 ins.)	75—100 cm. (30—40 ins.)	0—25 cm. (10 ins.)	75—100 cm. (30—40 ins.)
Potash	.05 (.07[1])	.048 (.077[1])	.022 (.043[1])	.063 (.102[1])	.036 (.043[1])	.097 (.101[1])	.104 (.163[1])	.076 (.123[1])	.110 (.168[1])
Lime	.07	.113	.033	.042	.023	.193	.154	.150	.125
Magnesia	.37	.285	.144	.067	.074	.283	1.415	.198	.099
Ferric Oxid	21.53	17.600	19.653	15.333	18.733	7.305	7.497	13.920	11.707
Alumina	12.40	9.621	11.217	18.941	16.413	14.298	14.504	5.223	5.531
Silica / Titanic Acid	.99	2.043	2.853	.366	1.250	.047	.108	.227	.120
Phosphoric Acid	.30	.179	.213	29 096	.187	.064	.224	.131	.205
Org. Matter and Water	18.49[2]	17.288	12.770	29.146	16.332	23.335	12.299	10.514	9.549
Nitrogen in Soil	.30	.447	.186	.697	128	.187	.079	.164	.103
Hygr. Moisture	6.80	15.062.	13.242	15.288	12.862	20.065	15.329	14.811	16.498

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[1] Determination made after boiling with acid for one hour.

[2] Soil air-dry.

he has not determined either the true humus or its nitrogen-content, it remains uncertain whether or not a sufficiency is in an available form, and whether their case may not be like that of the Hawaiian soil mentioned above (chapter 19, p. 362), in which despite 10% of humus and .17% of nitrogen, the land was found to be nitrogen-hungry. Again, as regards the phosphoric acid, which Wohltmann considers satisfactory to high, it is questionable to what extent it is rendered unavailable by the very high content of ferric hydrate. We are thus left in some uncertainty as to the real manurial requirements of the Samoan soils, which doubtless represent very closely also those of Tutuila, the chief American island of the group.

It is probable that for crops requiring so much potash as do the banana and cacao trees, potash is the first need when they cease to produce well on these soils.

Soils of Kamerun.—In the soils of Kamerun, also analyzed by Wohltmann, and of which two are placed alongside of those of Samoa, it is at once seen that the materials from which they have been formed are richer in both potash and lime than the parent rocks of the Samoan, and not quite so rich in iron. They are also very rich in organic matter, evidently down to the depth of a meter, as are those of Samoa. It is probably due to the high humus-content that these soils, washed as they have been by the second-highest rainfall in the world (about 35 feet annually) have not been as thoroughly leached as have been those of the Brahmaputra valley. The annual rainfall of Samoa is only from nine to eleven feet on the lower levels, but ranges as high as 18 feet at higher elevations.

It is noticeable that in most of these true tropical soils the content of magnesia is considerably above that of lime; a fact readily intelligible from the more ready solubility of lime in carbonated water. It is hardly doubtful that this disproportion will in many cases explain a lack of thriftiness, which could be effectually remedied by a simple application of lime or marl, without resorting to the more costly fertilizers.

THE SOILS OF MADAGASCAR.

The soils of the island of Madagascar have been analyzed to the number of about 500 by Müntz and Rousseaux, under the auspices of the French government.[1] So large a number of

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[1] Annales de la Science Agronomique, tome 1er, 1901, fasicules 1, 2, 3.

analyses should give a very full understanding of the agricultural capacity and adaptation of so comparatively limited an area; unfortunately, we are here again confronted by more or less imperfect data accompanying the samples collected by government agents, and by the use of an analytical method different from those of all other nations, and hence incommensurable except, as in the case of Wohltmann's method, in regard to certain ingredients.

The French chemists use nitric instead of chlorhydric acid; cold for phosphoric acid and lime, boiling-hot for five hours for potash; considering the remainder as of no practical importance. Since nitric acid is in general much less incisive than chlorhydric in its solvent power, comparison with the analyses made by other nations becomes difficult. As in the case of Wohltmann, magnesia, lime, and phosphoric acid may be considered to be quite thoroughly extracted by the treatment; while extraction of possibly available potash is doubtless very incomplete. On the whole, however, the estimates of soil-fertility based on percentages is very nearly the same as those assigned by Wohltmann in the table given above. Like Wohltmann, they emphasize the axiom that the same percentage-gauge of fertility cannot be applied in the tropics as in the temperate zones.

General Character of the Island.—The island of Madagascar, lying between the 11th and 25th degrees of south latitude, is quite mountainous in its central and eastern portion, where the coast falls off pretty steeply into the sea, leaving only a narrow coast belt of properly agricultural land in the lower valleys and at the mouth of the torrential streams. The mountains rise at one point to the height of nearly 10,000 feet. The western portion of the Island is much less broken, has much plateau land with low intersecting ranges and streams of moderate fall, with considerable alluvial lands near the coast. The rocks are almost throughout gneisses and mica-schists, which, as heretofore stated (chapter 4, p. 51), form mostly poor soils. There are a few areas of eruptive rocks and tertiary calcareous deposits, and on these the lands are much more thrifty. The rocks and red soils of the central mass, however, extend seaward almost everywhere.

The rainfall is high on the east side, where the moisture of the southeast trade winds is first condensed, the precipitation reaching ten to twelve feet (120 to 144 inches) annually. The western portion is relatively dry, but rains fall more or less throughout the year; while in the eastern and central mountainous part there is a distinct subdivision into a wet and a dry season. Here, while the rivers are largely torrential, many large fertile valleys have been created by the heavy denudation of the mountain slopes. This is especially the case in the Imerina province (in which the capital, Tananarivo, is situated), and here the valley soils are deep, and rich in humus. The western portion is but thinly forested. The soils of most of the island are "red" with ferric hydrate, resembling the laterite soils elsewhere; yet the iron percentages are not usually very heavy, ranging mostly from 4 to 6, more rarely to 10% and more, of ferric oxid. Most of the red soils are clayey, crack open in summer and become very hard in drying.

Of the 476 soils analyzed by Müntz and Rousseaux, 156 are from the province of Imerina, 56 from the adjacent province of Betsileo, therefore 212 from the central, mountainous part of the island. The remainder are scattered around the coasts; the most productive being apparently those of the northern end, Diego Suarez, which is mostly underlaid by the eruptive rocks forming the mountain mass of Mount Amber, from which numerous fertile valleys radiate. The valleys of the west coast also, in the provinces of Bara, Tulear and Betsiriry, have some very productive soils.

The subjoined table, giving fourteen analyses selected as representative from the mass of material presented by Müntz and Rousseaux, gives a fair general idea of the character of the soils of the great island. It is at once apparent that lime and potash are extremely deficient in the soils of the mountain slopes of central and southern Madagascar, these substances having, as elsewhere in the humid region, been leached down into the valleys; and the materials being mostly quite clayey, these valley soils have not, as in the case of the sandy alluvium of the Brahmaputra, themselves been again leached of their mineral ingredients. Practically these valleys seem to form the only profitably cultivable area of the central portion; while along the larger river courses, such as the Mangoky, Ikopa, Mahajamba and others, good alluvial "bottoms" and deltas

ANALYSES OF MADAGASCAR SOILS BY MUNTZ AND ROUSSEAUX,

	Imerina.			Betsileo	Tulear.	Maintirano.		Majunga.	Diego Suarez.		Andevorante.		Ambatondrazaka.	
	Central Mountain Region.				West	Coast.			N. C	oast.		East	Coast.	
Number of Soil.	4—4	115	71—4	272	253	261	No. 267	343	3	331	.107	370	81	105
Locality.	Ambohitromby.	Ankazobe North.	Ambohibzaka.	Fandrandava Valley.	R. bank of Sakondry north of Tongobory Valley.	Plateau of Antsoamena.	Village of Anhozorabe South of Mandroso.		Anamakia.	Montagne d'Ambre.	Dist. of Vatomandry. Ampitamafana.	Ambanimanhovinana.	Imerimandroso.	Sabotsy.
	Red Soil.	Ochreous Soil.				Sandy soil.		Hill summit.	Ochr 'us earth.	Ochr'us earth.	Plain valley, sandy soil.	Valley.		Alt. 1000 M.
Potash (K_2O)	.020	.006	.071	.017	.086	.015	.014	.012	.161	.031	.069	.012	.490	.005
Lime (CaO.)	.350	.060	traces	trace	4.180	trace	trace	trace	.620	trace	.070	trace	1.200	.070
Magnesia (MgO.)	.022													
Ferric Oxid (Fe_2O_3)	9.333													
Phosphoric Acid (P_2O_5)	.050	.032	.061	.267	.083	.043	.011	.017	.380	.415	.047	.161	1.566	.369
Nitrogen (N)	.096	.027	.030	.020	.075	.051	.039	.043	.124	.177	.016	.254	.249	.164
Remarks	Small cultural resource	Deficient in plant-food ingredients. May maintain vegetation on account of humidity.	No great cultural resource.	Only moderately fertile.	Potatoes, manioc, represents soil of whole region.	Manioc, maize, beans, peanuts, coco-trees, mangoes	Remarkable crops, manioc, rice.	Grasses, tall herbs	Promises considerable fertility.	Crops, coffee. Good cultural resources.	Coffee, vanilla, rice, &c., rich red soil. Rep. whole valley.	Very fertile soil.	Amply rich in plant food suited for intensive cultures.	Fertile soil fit for all cultures.

form available lands. It seems to the writer that, in view of their own expressed opinion that tropical soils are not to be gauged on the same percentage-basis of soil-ingredients as those of temperate regions, Müntz and Rousseaux rather underestimate the productive value of many of these lands; regarding which the field notes report good production, and the crops of which are certainly not the first that they have borne in the course of Malagassy history. It is as though their anxiety to forestall overestimates of agricultural prospects by intending settlers, had led them to somewhat overshoot the mark.

Be that as it may, the influence of the tropical climate and rainfall upon the composition of these soils is certainly very marked. While gneiss is not credited with producing first-class soils, its usual content of orthoclase feldspar should at least insure a respectable average content of potash; but this, it will be seen, is mostly not the case; and that of lime seems even worse, aside from the case where, as in some regions near the coast (especially in the west and south), calcareous formations, probably of tertiary age, have contributed to soil-formation. At some points there seem to exist phosphate deposits, well known elsewhere to occur in such rocks, which impart to the soils exceptionally high percentages of phosphoric acid, even exceeding one per cent. The phosphates of course remain practically untouched by the leaching processes, and appear to be somewhat widely diffused; so that the soils of Madagascar may be said to be, on the whole, well supplied with this important plant-food.

In the central province of Imerina the valleys and lower slopes show a fair content of both lime and potash; but in the province of Betsileo, adjoining it on the south, nearly every one of the soils analyzed is reported as containing only "traces" of lime, together with very small amounts of potash in most cases. The ultimate analyses of ignited red earths, of which an average is here given, are of interest in this connection.

ULTIMATE ANALYSIS OF IMERINA RED SOILS, IGNITED; AVERAGE OF THREE.

Silica	55.2
Potash	.3
Lime	trace
Magnesia	1.1
Ferric oxid	10.6

It is quite obvious that only leaching-down and concentration of the feeble resources of such material in the valleys can produce soils worthy of permanent cultivation.

One point, however, is strikingly illustrated in several of the analyses given in the subjoined table. We find in the original quite a number of cases in which the field notes report considerable fertility, while the chemists' judgment is very unfavorable. Thus we find recorded for the soil No. 267, taken near the village of Anjozorabe, in the Maintirano region, "luxuriant vegetation and remarkable crops," with such minute proportions of potash, lime and phosphoric acid that the authors are compelled to say that the land offers "no cultural resources." The same occurs in the cases of soils Nos. 370, 261, and several others having either "good crops" or "abundant natural vegetation." Unless we assume that in these cases the samples were not properly taken, we are obliged to conclude that under the local climatic conditions, such minute amounts of plant-food are developed with sufficient rapidity to supply good growth. This would be quite parallel to the case of the tea soils of Assam, whose production lasted 30 years before showing exhaustion, on plant-food percentages only slightly greater than those here noted, and determined by a much more incisive method.

It is thus quite obvious that a different standard of interpretation must be applied to tropical soils as compared with either the temperate humid, or the arid regions; and that uniform methods of analysis are needed to evolve a definite rule from the present uncertainties.

THE SOILS OF INDIA.

The soils of India have been investigated to some extent by the geological survey of India; by Voelcker, who went there on a special mission to investigate agricultural conditions; and since, more especially by Leather, Bamber and Mann; and by Moreland. Leather's account is the most complete on the general subject and can best serve as the basis for a review of the entire peninsula.[1]

According to Dr. Leather, "the four main types of soils to

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[1] On the Composition of Indian Soils. Agr. Ledger, 1898, No. 2.

be dealt with, and which certainly occupy by far the larger of the Indian cultivated area," are: *The Indo-Gangetic alluvium,* covering the chief cultivable areas of the Indo-Gangetic plain; the *black cotton soils or regur,* occupying the main body of the plateau of the Central provinces (the Deccan) from the Vindhya range south; the *red soils* lying on the metamorphic rocks of Madras; and the *" laterite " soils* which are met with in many parts of India. To these should be added the *alluvial soils of the Brahmaputra valley,* in Assam. It is hardly to be expected that so large an area as that of India, with its diversified topography, and a climate ranging from about four inches of rainfall in the northern Pandjab to the world's maximum in Assam, and southward to typical tropical conditions, could be even thus briefly characterized. The observers have rarely given for the several soils analyzed, special local and climatic data, which cannot always be obtained from the official publications; so that it is not easy to discuss them from the points of view of aridity and humidity.

The Indo-Gangetic Plain.—The general rain-map of India shows the Pandjab and Rajputana to be arid throughout; thence eastward the rainfall increases to 25 and 30 inches on the Ganges; notwithstanding which, alkali (reh) is abundant about Aligarh, Meerut and Agra. Thence toward Calcutta there is a steady increase of rainfall until, at the head of the Bay of Bengal, 70 inches is reached.

If under these conditions the Indo-Gangetic plain admits of any generalizations as regards soil composition, it must be attributed in the main to its predominantly alluvial character. It should therefore be relatively rich in lime, magnesia and potash. So far as the first is concerned, Leather remarks that the only rocky particles larger than sand to be found in all this large belt of land is the nodular limestone called kankar, formed by the deposition of calcium carbonate within the soil, at the depth of a few feet. It occurs very generally in India, and as stated above (chapters 9 and 19), this occurrence of calcareous hardpan, of varying hardness, is almost universal in the arid regions. The analysis given in the table, selected as representative from those given by Leather, show that the general forecast is realized in them, as soils of an arid region.

ANALYSES OF SOILS OF INDIA.

NORTHERN INDIA. SOUTHERN INDIA.

	Indo-Gangetic Alluvium.				Brahmaputra Alluvium.				Laterite Soils.			Madras Presidency.								
	Panjab.		Lower Ganges.		Assam.[1]				Bengal.			Laterite Soil.	Upland. Red Soils.		Alluvium. Averages.		Regur.			
	Sotar Valley. Clay Loam.[2]	Changa Manga. Loamy soils.	Ison, Ganges, Doab. Sandy Loams.	Sibpur, Calcutta. Clay soils.	Fezpur bank. Old Alluvium.	Lakhimpur. New Alluvium.	Golaghat. Nigriting. New Alluvium.	Sipsagar. Teela land. New Alluvium	Lohardaga.	Chota Nagpur. Singhbhum District.	Hazaribagh District.	Saidapet.	Madura. Dindigal.	Trichinopoli. Parambalur.	Loamy Soils.	Sandy Soils.	Regur. Average 18 Soils.	Trichinopoli. Parambalur Taluk.	Kistna. Narsaopet.
Insoluble matter	81.57	81.54	88.08	73.58	85.18	84.60	85.88	91.52	29.67	59.06	80.46	76.86	90.47	86.74	71.79	93.09	68.41	65.16	68.29
Soluble silica	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......	......
Potash (K_2O)	.74	.54	.64	......	.35	.24	.26	.14	.10	.27	.38	.09	.24	.05	.22	.04	.41	.14	1.14
Soda (Na_2O)	.08	.25	.09	1.82	.30	.12	.23	.16	.04		.32	.17	.12	.15	.17	.07	.31	.01	1.30
Lime (CaO)	1.44	.98	.47	1.01	.04	.11	.03	.06	.38	.28	1.72	Trace.	.56	.48	.54	.13	2.90	2.18	3.43
Magnesia (MgO)	1.97	1.72	.32	1.64	.46	.33	.36	.20	.21	.33	.38	.77	.70	.70	1.29	.33	2.27	2.47	1.94
Br. ox. of Manganese (Mn_3O_4)	......	.11	......	7.19	......	......	......	......	.07	.48	.50	.19	.08	.10	.13	.04	.17	.25	.09
Peroxid of iron (Fe_2O_3)	4.32	5.11	3.10	7.58	2.08	2.78	2.74	1.52	48.71	26.64	6.12	10.09	3.51	5.70	9.59	2.46	7.13	9.27	6.96
Alumina (Al_2O_3)	5.85	4.36	4.38	9.89	5.03	5.63	5.10	3.30	8.81	7.27	7.19	8.84	2.92	5.68	9.98	1.74	10.14	13.76	10.28
Phosphoric acid (P_2O_5)	.23	.14	.08	.07	.05	.06	.06	.06	.64	.08	Trace.	Trace.	.09	.05	.11	.05	.06	Trace.	.00
Sulfuric acid (SO_3)	?	.02	.05	.00	.02	.02	.02	.02	......	......	Trace.	......	......	......	......	......	......	Trace	Trace.
Carbonic acid (CO_2)	1.13	.45	.37	.28	......	......	......	......	.06	.16	.12	.12	.30	.11	.09	.11	1.62	.91	1.88
Water and org. matter	2.67	4.78	2.42	5.93	5.59	6.11	5.32	.18	11.31	5.43	2.81	2.87	1.01	.24	6.09	1.94	6.58	5.85	3.96
Total	100.00	100.00	100.00	100.00					100.00	100.00		100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.27
Nitrogen	.02	.082	.027	.051	.14	.20	.18	.08	.010	.024	.03	.015	.006	.021	.037	.015	.03	.024	.018

[1] Analyses by Maun.

[2] Analysis by Voelcker.

The Brahmaputra Alluvium in Assam.—Aside from the immediate alluvium of the Indus, of which no definite data are available, the Indo-Gangetic plain represents the drainage of the *southern* slope of the Himalaya chain. That of most of the *northern* slope is represented by the Brahmaputra, which not only orginates in a region of heavy precipitation—Thibet— but continues in the same throughout its course, and rounding the easternmost spur of the Himalaya range enters, in southern Assam, upon the region of the maximum rainfall known. Its alluvial deposits should therefore show the reverse characteristics of those of the Ganges; they should, as thoroughly leached soils, be poor in lime, magnesia and potash. We have fortunately on this subject the excellent work done by Mr. H. H. Mann for the Indian Tea Association, the report of which was published in 1901, and contains, besides a large number of analyses, good descriptions of the general soil and cultural conditions of the Assam tea districts, with suggestions for their improvement.

No.!

The tea plantations of Assam are located almost wholly on the new and old alluvium of the Brahmaputra river, bordered on the north by the eastern spur of the Himalayas, on the south by the low ranges of the Khasia hills. The soil is mostly quite sandy, the late alluvium gray in color, the older reddish and more loamy. Of the four analyses given in the table and fairly representing the average character of these soils, the two first are from the north side, the latter two from the south side of the river.

It will be noted that the prominent feature of all these soils is an extremely low percentage of lime, the general average being about .08% as against nearly 1.0% in the average Indo-Gangetic soils. In the latter, potash ranges between .65 and .70%; in the Assam soils between .25 and .35. Magnesia averages nearly 1.3 in the Indo-Gangetic, against about .50 in the Assam tea soils. It is thus apparent that the same general facts as regards the leaching-out of soil ingredients already shown for eastern and western North America are strikingly verified in northern India; but reversed as regards the points of the compass. The preferential leaching-out of lime as compared with magnesia and potash, is here again well exemplified. It would be interesting to have an analysis of the Brahmaputra water to compare with that of the Ganges. That tea should flourish for twenty to thirty years in such soils, is a good indication of one cause at least of the total failure of tea culture in California, where tea plants are difficult to maintain alive, and after 25 years form rounded, scrubby bushes not over four feet high. Similar failures of tea on calcareous soils are on record from India. The low lime-content of the Assam soils, then, does not necessarily imply that these soils should be limed to maintain tea production. According to Mann, the main deficiency is in nitrogen, as the figures imply; but whether his recommendation of green-manuring with leguminous crops to increase the nitrogen-supply is practicable without first supplying more lime to the Assam soils, is questionable. Since phosphoric acid is also low, his recommendation to use freely the basic or Thomas slag is doubtless a good one, since lime would thus also be moderately increased.

Bamber gives a number of analyses of tea soils from low ground in Assam, which are very rich in vegetable matter and quite acid. Like those reported by Leather, these " bhil " soils are very poor in lime and nitrogen, but fairly supplied with potash and phosphoric acid.

The Regur or Black Cotton Soils of Southern India.—The second-greatest reasonably uniform soil-area of India is that covered by the regur, or black cotton soils, in south central India, notably the Deccan, where these soils are said to have been cultivated without fertilization for 2000 years and are still fairly productive.[1] Both in their physical character, chemical composition, and cultural characteristics, these regur soils are very similar to the " prairie soils " of the Cotton states and especially to the " black adobe " of California. Like the latter they are of unusual depth without change of tint; they crack wide open during the dry season on account of their high clay content; and the soil is thus partly inverted by the surface soil falling into the cracks. To the latter fact Leather as-

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[1] That is to say, they now produce about 600 pounds, or 10 bushels of wheat per acre, as do the Rothamstead soils after fifty years' exhaustive cultivation. Probably both have come down to the permanent level of production corresponding to the amount of plant-food made currently available each year by the fallowing process in originally very rich soils. The present product of cotton on the regur lands does not seem to be on record; judging by the wheat product it should not be over one hundred pounds of lint per acre.

cribes, in part, the long duration of fertility in the regur lands. The regur also contains fragments of calcareous hardpan (here called guvarayi), just as in the Great Valley of California. The eighteen analyses of regur given by Leather agree so nearly in their essential points that it is admissible to average them; two other examples are however also given in the table.

It will be noted that while the contents of lime, magnesia and alumina are uniformly high, the content of potash has a wide range; it rises very high (1.14%) in the maximum, while the average is fair.

One conspicuous defect of these soils is their extremely low content of nitrogen, in view of which their lasting productiveness is difficult to understand; unless it be that, as in California, their high lime-content causes a copious crop of leguminous weeds, constantly replacing the nitrogen supply.[1] Unfortunately we have no determinations of humus or of its nitrogen-content. Leather attributes the black color of the regur to some mineral substance rather than to humus; but his arguments are not quite convincing, so long as the Grandeau test has not been made. In view of the low rainfall and the closeness of the texture of regur, it is probable that little if any nitrates are currently washed out of the black cotton lands.

The regur soil-sheet seems to be underlaid over the greater part of its area by a basaltic eruptive sheet (not by metamorphic rocks, as stated by Leather), and it is not easy to conceive how such a soil stratum can have been formed from such rocks as a sedentary formation. Elsewhere such soils are usually rather light and porous, as is the case in the Hawaiian and Samoan islands; and very high in iron-content. The regur has the character of an alluvial backwater or lake deposit; but how such a formation can have occurred on the Deccan plateau, is a question not easily answered.

Red Soils of the Madras Region.—Interspersed with and to seaward of the regur lands there are in the Madras presidency considerable bodies of "red" lands, which appear to be sedentary soils formed from underlying dark-colored, mostly eruptive rocks. Some of these are very rich in lime and potash, others very poor, and it seems impossible to classify them

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[1] See Voelcker, Report on the Improvement of Indian Agriculture, 1892, p. 46 par. 60.

under any definite category either from the chemical or physical point of view, except as to their red tint. Even this tint, however, is not always found associated with exceptionally high contents of iron oxid, but due rather to its fine diffusion in the soil mass. As compared with the regur, with which the "red" areas are interspersed, these soils contain, on the average, less lime, potash and ferric oxid; and phosphoric acid is uniformly low. The alluvial (brown and black) soils from the same region, exemplified in the table, are doubtless derived partly from the regur, and their color and composition varies accordingly.

"Laterite Soils."—These are defined by Wohltmann (Tropische Agricultur, 1892) as being "the characteristic sedentary soils (Verwitterungsböden) of the tropics, formed under the influence of heavy precipitation, high temperatures and drought." This definition does not indicate their derivation from any particular rock, such as laterite is supposed to be; but its definition puzzles even geologists, and so, as Leather observes, the definition of laterite soils will naturally puzzle agricultural chemists. Accordingly it is difficult to deduce from the analyses given any definite common characters. Leather describes those analyzed by him as red or reddish, sandy and gravelly, the gravel or cobbles often incrusted with a dark-smooth crust of limonite, which to the uninitiated looks as though the rock itself had been fused and vitrified. The samples from Lohardaga and Singhbhum show the effects of these limonite crusts upon the composition of the soils, which resembles that of the Hawaiian soils mentioned above; but in the latter the iron oxid is wholly pulverulent. But it is probable that, as in the case of the latter, the high content of phosphoric acid shown in the statement (.64 for the Lohardaga soil) is tightly locked up in the insoluble form of ferric phosphate. Wohltmann's definition of laterite soils seems best represented by the "terra roxa" of Brazil, which as he states has .02 to .08% of potash, .02 to .10% of lime, and .045 to .10% of phosphoric acid. Humus and nitrogen are very deficient in all these soils.

While most prominent in the coast region of Bengal, they also occur not only near Madras (Saidapet) but also in the belt of high rainfall on the Malabar (western) coast of the Indian peninsula.

The productiveness of the laterite soils seems throughout to be only moderate, yet much higher than would be expected of soils of similar composition in the temperate zones, where the rate of soil-formation is so much slower than in the tropics.

From the analyses of "coffee soils" from Yarcand in the Sheveroy hills, north of Madras, we learn that coffee does well with a fairly liberal supply of lime (.30 to .44%) and phosphoric acid, but is satisfied with a much smaller amount of potash than is found in the tea soils of Assam.

A farther systematic investigation of the soils of India, with simultaneous accurate observations on their depth, subsoil, geological derivation, topographical location and relations to rainfall, could not fail to yield very important practical results. The examination of samples collected and sent in by persons unfamiliar with the proper mode of taking soil specimens, and the information which should accompany them, always involves a great deal of uncertainty and waste of labor, and indefiniteness of results.

INFLUENCE OF ARIDITY UPON CIVILIZATION.

In connection with the facts given and discussed above, as to the relative productive capacity of lands of the humid and arid regions, it becomes of interest to consider what influence, if any, these differences may have had in determining the choice of the majority of the ancient civilizations in favor of countries where nature imposes upon the husbandman, who supplies the prime necessaries of life, the onerous condition of artificial irrigation.[1]

Preference of Ancient Civilizations for Arid Countries.—A brief review suffices to establish the fact of such choice. Aside from Egypt, the permanent fertility of which is ascribed to the inundations of the Nile, we find to westward the oases of the Libyan and Sahara deserts, the high fertility of which has become proverbial and has caused them to be cultivated from ancient times to the present. Similarly, on both sides of the

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[1] **Verhandlungen der Deutschen Physiologischen Gesellschaft in Berlin, December, 1892; North American Review, September, 1902.**

Mediterranean Sea, we find that, instead of the humid forest country, it was in the arid but irrigable coast countries, such as the vegas of Valencia, Alicante, Granada, Malaga, and the even more arid domain of which Carthage was the metropolis; and farther east, in the Graeco-Syrian archipelago and the adjacent coasts, that noted centers of civilization were developed and maintained. Thence the arid belt requiring irrigation extends from Egypt and Arabia to Palestine, Syria, Assyria, Mesopotamia and Persia, and across the Indus through the anciently recognized regions of Indian civilization—Sindh, the Panjab, Rajputana and the Northwestern provinces—to the Ganges, embracing such well-known centers as Lahore, Delhi, Meerut, Agra, etc., inhabited by much more hardy and progressive races than the humid and highly productive tropical portions of the Indian peninsula. Throughout the extensive and important portion of northern India, irrigation is necessary to maintain regular production; and in default of it, periodic famines ravage the country. Thousands of years ago, millions upon millions of treasure were expended there upon irrigation works, as has again been done in modern times; yet in the rainy, forested districts we still find large areas practically tenanted by wild beasts. In Asia Minor, as well as in Central Asia, the remains of ancient cities once surrounded by richly productive irrigated fields, are found where at present only the herds of nomads pasture. The Khanates of southern Turkestan with their historic cities, illustrate the same obstinate bias in favor of arid climates. Similarly, in the New World, it was not in the moist and exuberantly fertile forest lands of the Orinoco and Amazon, but on the arid western slopes of the Andes, that the civilization of the Incas was developed. In Mexico, also, it was the high central, arid plateau, not the bountifully productive *tierra caliente,* over which the Aztecs chose to establish the main centers of their empire. Even to northward, the inhabitants of the high, dry plains of Arizona and New Mexico were, as their descendants of the Pueblos are to-day, superior in social development to their forest-dwelling neighbors of the Algonquin race. From time immemorial they have practiced irrigation in connection with cultivation, maintaining a comparatively dense population on very limited areas.

It might be thought that the desire to avoid the labor of clearing the forest ground was the motive which guided the choice of the ancient nations toward the cheerless-looking, treeless regions.

But if we consider the cost and labor of establishing and maintaining irrigation ditches, it certainly seems that a stronger motive, based on the intrinsic nature of the case, must have influenced their selection. Neither can we with any degree of plausibility ascribe the preference for the arid open country to the fear of enemies lurking in the forest, since war was in early times practically the normal condition of mankind, and was waged with little hesitation wherever booty was in sight. It has also been asked how the ancients could have known of the high productive capacity of arid lands; but no one who has ever seen the springing-up of luxuriant vegetation after the periodic overflows of the arid-region streams, or the same surrounding the springs in the deserts, would ask that question.

Irrigation necessitates Co-operation.—Irrigation enterprises can be accomplished in a very limited degree only by individuals or even families. Its permanently successful execution requires the co-operation of at least several social groups, ultimately of communities and states, if it is not to give rise to acrimonious contentions or actual warfare; witness the " shotgun policy " resorted to in the arid West in times not very remote. Irrigation, in other words, compels co-operative social organization quite different from and far in advance of that necessary in humid countries. And such organization is manifestly conducive to the preservation and development of the arts of peace, which means civilization. The most ancient systematic code of laws known to us is that of Hammurabi, the king of arid Assyria.

The high and permanent productiveness of arid soils induces permanence of civil organization.—In humid countries, as is well known, cultivation can only in exceptional cases be continued profitably for many years without fertilization. But fertilization requires a somewhat protracted development of agriculture to be rationally and successfully applied in the humid regions, and the Germanic tribes, like the North-American Indians, seem to have shifted their culture grounds frequently in their migrations. No such need was felt by the inhabitants of the arid regions for centuries, for the native fertility of their soils, coupled with the fertilizing effects of irrigation water bringing plant-food from afar, relieved them of the need of continuous fertilization; while in the humid regions, the fertility of the land is currently carried into the sea by the drainage waters, through the streams and rivers, causing a chronic depletion which has to be made up for by artificial and costly means. What with the greater intrinsic fertility and the great depth of soil available for plant growth, much smaller units of land will suffice for the maintenance of a family in arid countries; a fact which is even now being illustrated in the irrigated region of the United States, where ten acres of irrigated land instead of 40 or 160, as in the East, form the unit.

The arid regions were, therefore, specially conducive to the establishment of the highly complex polities and high culture, of which the vestiges are now being unearthed in what we are in the habit of calling "deserts;" the very sands of which usually need only the lifegiving effects of water to transform them into fruitful fields and gardens. It is also quite natural that the wealthy and prosperous communities so formed should in the course of time have excited the cupidity of the "barbarous" forest-inhabiting races, and as history records, have been over and again overwhelmed by them—a similar fate often afterwards overtaking the conquerors in their turn, after the Capuan ease of their existence had weakened their warlike prowess. At the present time, the arid regions of the old world are still largely suffering from having been overrun by the nomadic Turanians, whose original habitat—Mongolia and Turkestan—while also arid, does not permit of the ready realization of the advantages above outlined, on account of the rigorous climate brought about by altitude. Mahometanism first expelled, and has since repelled, occidental civilization from the arid regions of the Old World, remaining to-day as an obstacle to its progress. The peaceful aggression of railroads and telegraphs now seems likely to gradually overcome this repulsion; and when Constantinople and Bagdad shall be linked together by the steel bands, the desert will lose its terrors, and Mesopotamia and Babylonia will again become garden lands, as of old, under the abundant waters of the Euphrates and Tigris. Until the water-supplies of the arid countries shall have been more definitely gauged, it is impossible to foretell to what extent food-production may be increased by their cultivation under irrigation, after the relief from political misrule shall have rendered such undertakings safe. But it can even now be foreseen that with improved modern methods of cultivation, the productive area of the world can be vastly increased by the utilization of the countries where, as the Turcomans say, " the salt is the life of the land."

CHAPTER XXII.

ALKALI SOILS.

Alkali Lands and Sea-shore Lands.—Alkali lands proper, as already stated, are wholly distinct in their nature and origin from the salty lands of sea-coast marshes, past or present. The latter derive their salts from sea-water that occasionally overflows them, or from that which has evaporated in segregated basins or estuaries; and the salts impregnating them are essentially "sea salts," that is, common salt, together with bittern (magnesium chlorid), Epsom salt (magnesium sulfate) gypsum, etc. (see chapter 2, p. 26). Very little of what would be useful to vegetation or desirable as a fertilizer is contained in the salts impregnating such soils; and they are by no means always intrinsically rich in plant-food, but vary greatly in this respect.

While sea-shore lands are by no means always of high fertility even when freed from their salts, especially when very sandy, it is otherwise when they occur near the mouths of streams or rivers, whose finest sediments they then receive. From such lands are formed the profusely productive Polders of Holland and northern Germany, and the equally noted "colmates" of France and Italy. These, so soon as freed from salt, may be considered as possessing the same advantages as "delta" alluvial lands, and from the same causes; notably the accumulation of the finest sediments derived from the rivers' drainage basins.

Origin.—Alkali lands proper bear no definite relation to the present sea; they are mostly remote from it or from any other sea bed, so that they have sometimes been designated as "terrestrial salt lands." Their existence is in the majority of cases definitely traceable to climatic conditions alone. They are the natural result of a light rainfall, insufficient to leach out of the land the salts that always form in it by progressive weathering of the rock powder of which all soils largely consist. Where the rainfall is abundant, that portion of the salts corresponding to "sea salts" is leached out into the bottom water, and with this passes through springs and rivulets into the country drainage, to be finally carried to the ocean.[1] Another portion of the salts formed by weathering, however, is partially or wholly retained by the soil; it is that portion chiefly useful as plant food.

It follows that when, in consequence of insufficient rainfall, all or most of the salts are retained in the soil, they will contain not only the ingredients of sea-water, but also those useful to plants. In rainy climates a large portion even of the latter is leached out and carried away. In extremely arid climates, on the contrary, the entire mass of the salts remains in the soils; and, being largely soluble in water, evaporation during the dry season brings them to the surface, where they may accumulate to such an extent as to render ordinary useful vegetation impossible; as is seen in "alkali spots," and sometimes in extensive tracts of 'alkali desert." Three compounds, viz. the sulfate, chlorid and carbonate of sodium, usually form the main mass of these saline efflorescences. Magnesium sulfate (Epsom salt) is in many cases a very abundant ingredient; some calcium sulfate is nearly always present, and calcium chlorid is not infrequently found.

In some cases the above salts are in part at least derived from the leaching of adjacent or subjacent geological deposits impregnated with them at the time of their formation. Such is the case in portions of Wyoming, Colorado and New Mexico, in the Colorado river delta, and in the Hungarian Plain; and it is in these cases especially that the chlorids of calcium and magnesium also form part of the saline mixture.

Geographical Distribution of Alkali Lands.—In looking over a rainfall map of the globe[2] we see that a very considerable portion of the earth's surface, forming two belts to poleward of the two tropics, has deficient rainfall; the latter term being commonly meant to imply any annual average less than 20 inches (500 millimeters). The arid region thus defined includes, in North America, most of the country lying west of the one hundredth meridian up to the Cascade Mountains, and

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[1] See Chapter 2, p. 26.

[2] See above, chapter 16, p. 294.

northward beyond the line of the United States; southward, it reaches far into Mexico, including especially the Mexican plateau. In South America it includes most of the Pacific Slope (Peru and Chile) south to Araucania; and eastward of the Andes, the greater portion of the plains of western Brazil and Argentina. In Europe only a small portion of the Mediterranean border is included; but the entire African coast-belt opposite, with the Saharan and Libyan deserts, Egypt and Arabia, are included therein, as well as, south of the Equator, a considerable portion of South Africa (Kalahari desert). In Asia, Asia Minor, Syria (with Palestine), Mesopotamia, Persia, and northwestern India up to the Ganges, and northward, the great plains or steppes of central Asia eastward to Mongolia and western China, fall into the same category; as does also a large portion of the Australian continent.

Utilization of World-wide Importance.—Over these vast areas alkali lands occur to a greater or less extent, the exceptions being the mountain regions and adjacent lands on the side exposed to the prevailing winds. It will therefore be seen that the problem of the utilization of alkali lands for agriculture is not of local interest only, but is of world-wide importance. It will also be noted that many of the countries referred to are those in which the most ancient civilizations have existed in the past, but which at present, with few exceptions, are occupied by semicivilized people only. It is doubtless from this cause that the nature of alkali lands has until lately been so little understood, that even their essential distinctness from the sea-border lands has been but recently recognized in full. Moreover, the great intrinsic fertility of these lands when freed from the noxious salts, has been very little appreciated; their repellent aspect causing them to be generally considered as permanently waste lands.

Repellent aspect.—This aspect is essentially due to their natural vegetation being in most cases confined to plants useless to man, commonly designated as "saline vegetation,"[1] of which but little is usually relished by cattle. Notable exceptions to this rule occur in North and South America, Australia, and Africa, where the "saltbushes" of the former and the "karroo" vegetation of the latter form valuable pasture

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[1] See Chapter 23.

FIG. 60.—Alkali Lands in San Joaquin Valley, California.

and browsing grounds. Apart from these, however, all efforts to find culture plants for these lands generally acceptable, or at least profitable, in their natural condition, have not been very successful.

Figure 60 illustrates the usual aspect of alkali lands in the San Joaquin valley of California. It will be noted that the alkali-covered surface is only in spots, with clumps of vegetation between, so that cattle can find both pasture and browsing on a portion of such lands, even though the plants so growing are not usually of the most desirable kind. We find in all arid regions, however, considerable areas either wholly destitute of vegetation, or bearing only such saline growth as is rejected by all kinds of domestic animals.

Effects of Alkali upon culture plants.—In land very strongly impregnated with alkali salts, most culture plants, if their seed germinates at all, will show a sickly growth for a short time, "spindle up" and then die without fruiting. In soils less heavily charged the plants may simply become dwarfed, and fruit scantily. The effect on grown trees around which alkali has come up, is first, scanty leafage and short growth of shoots, themselves but sparsely clothed with leaves. This state of things is well shown in figures 61 and 62, which represent apricot trees growing but a short distance apart, but one coming within range of an expanding alkali spot. The characteristic sparseness of the foliage of the "alkalied" tree as compared with the adjacent one is well shown.

Nature of the injury to plants from Alkali.—When we examine plants that have been injured by alkali, we will mostly find that the visible damage has been done near the base of the trunk, or *root crown;* rarely at any considerable depth in the soil itself. In the case of green herbaceous stems, the bark is found to have been turned to a brownish tinge for half an inch or more, so as to be soft and easily peeled off. In the case of trees, the rough bark is found to be of a dark, almost black, tint, and the green layer underneath has, as in the case of herbaceous stems, been turned brown to a greater or less extent. In either case the plant has been practically "girdled," the effect being aggravated by the diseased sap poisoning more or less the whole stem and roots. The plant may not die, but it will be quite certain to become unprofitable to the grower.

It is mainly in the case of land very heavily charged with

Fig. 61.—Unaffected. APRICOT TREES ON ALKALI GROUND. Fig. 62.—Yielding to Alkali.

common salt, as in the marshes bordering the sea, or salt lakes, that injury arises from the direct effects of the salty soil-water upon the feeding roots themselves. In a few cases the gradual rise of salt water from below in consequence of defective drainage, has seriously injured, and even destroyed, old orange orchards. The natural occupancy of the ground by certain native plants may be held to indicate that the soil is too heavily charged with saline ingredients to permit healthy root growth or nutrition until the excess of salts is removed. (See below, chapters 23 and 26).

The fact that in cultivated land the injury is usually found to occur near the surface of the soil, concurrently with the well-known fact that the maximum accumulation of salts at the surface is always found near the end of the dry season, indicates clearly that this accumulation is due to evaporation at the surface. The latter is often found covered with a crust consisting of earth cemented by the crystallized salts, and later in the season with a layer of whitish dust resulting from the drying-out of the crust first formed. It is this dust which becomes so annoying to the inhabitants and travelers in alkali regions, when high winds prevail, irritating the eyes and nostrils and parching the lips.

Effects of Irrigation.—One of the most annoying and discouraging features of the cultivation of lands in alkali regions is that, although in their natural condition they may show but little alkali on their surface, and that mostly in limited spots, these spots are found to enlarge rapidly as irrigation is practiced. Yet since alkali salts are the symptoms and result of insufficient rainfall, irrigation is a necessary condition of agriculture wherever they prevail. Under irrigation, neighboring spots will oftentimes merge together into one large one, and at times the entire area, once highly productive and perhaps covered with valuable plantations of trees or vines, will become incapable of supporting useful growth. This annoying phenomenon is popularly known as "the rise of the alkali" in the western United States, but is equally well known in India and other irrigation regions.

The soil being impregnated with a solution of the alkali salts, and acting like a wick, the salts naturally remain behind on the surface as the water evaporates, the process only stopping when the moisture in the soil is exhausted. We thus not infrequently find that after an unusually heavy rainfall there follows a heavier accumulation of alkali salts at the surface, while a light shower produces no perceptible permanent effect. We are thus taught that, within certain limits, the more water evaporates during the season the heavier will be the rise of the alkali; provided that the water is not so abundant as to leach the salts through the soil and subsoil into the subdrainage.

Leaky Irrigation ditches.—Worst of all, however, is the effect of irrigation ditches laid in sandy lands (such as are naturally predominant in arid regions), without proper provision against seepage. The ditch water then gradually fills up the entire substrata so far as they are permeable, and the water-table rises from below until it reaches nearly to the ditch level; shallowing the subsoil, drowning out the deep roots of all vegetation, and bringing close to the surface the entire mass of alkali salts previously diffused through many feet of substrata.

Surface and Substrata of Alkali Lands.—Aside from the desert proper, in the greater portion of the alkali country "alkali spots," *i. e.* ground covered with saline efflorescences and showing little or no vegetation, are interspersed with larger areas apparently free from salts and covered with the ordinary vegetation of the region. A view of such country is given in a plate on a previous page. The alkali spots are usually somewhat depressed below the surrounding lands, and after rains remain covered with water for some time; the water frequently assuming a brown or blackish tint after standing.

When a pointed steel probe is pushed down within such an alkali spot, it will usually be found that, although the soil may appear quite sandy, it is penetrated with some difficulty; while outside of the spots, the probe does not encounter serious resistance until it reaches the depth of two or three feet, when it frequently becomes impossible to penetrate farther without the aid of a hammer. On the margin of the spots, the transition from utter barrenness to a luxuriant vegetation of native weeds is mostly quite sudden; as is shown in the figure, p. 425.

Vertical Distribution of the Salts in Alkali Land.—The results of a comparative examination of such land before and after irrigation,[1] are shown in the annexed diagrams; in which the kind and amount of salts is shown for every three inches of vertical depth, down to four feet, by curves whose extension from left to right indicate the several percentages, while the outer curved line gives the total of salts for each of the several depths.

Fig. 63 represents the condition of the salts in an "alkali spot" as found at the end of the dry season at the Tulare substation, California. The soil was sampled to the depth of two feet at intervals of three inches each. It is easy to see that at this time the bulk of the salts was accumulated within the first six inches from the surface, while lower down the soil contained so little that few culture plants would be hurt by them.

How Native Plants Live.—Fig. 64 represents similarly the state of things in a natural soil alongside of the alkali spot, but in which the native vegetation of brilliant flowers develops annually without any hindrance from alkali. Samples were taken from this spot in March, near the end of the wet, and in September, near the end of the dry season, and each series fully analyzed. There was scarcely a noticeable difference in the results obtained. It is seen in the figure that down to the depth of 15 inches there was practically no alkali found (0.035%), and it was within these 15 inches of soil that the native plants mostly had their roots and developed their annual growth. But from that level downward the alkali rapidly increased, and reached a maximum (0.529%), at about 33 inches; decreasing rapidly thence until, at the end of the fourth foot in depth, there was not more alkali than within the first foot from the surface. In other words, the bulk of the salts had accumulated at the greatest depth to which the annual rainfall (7 inches) ever reaches, forming there a sheet of tough, intractable clay-hardpan. The shallow-rooted native plants germinated their seeds freely on the alkali-free surface; their roots kept above the strongly-charged subsoil, and through them and the stems and foliage all the soil moisture was evaporated by the time the plants died. Thus no alkali was brought up from below by evaporation. The seeds shed would remain uninjured, and would again germinate the coming season.

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[1] Hilgard and Loughridge, Bulletin No. 128, California Experiment Station; Report California Experiment Station, 1894–95, p. 37; Bulletin No. 30, Office of Experiment Stations; Wollny's Forsch. Geb. Agr. Phys., 1896.

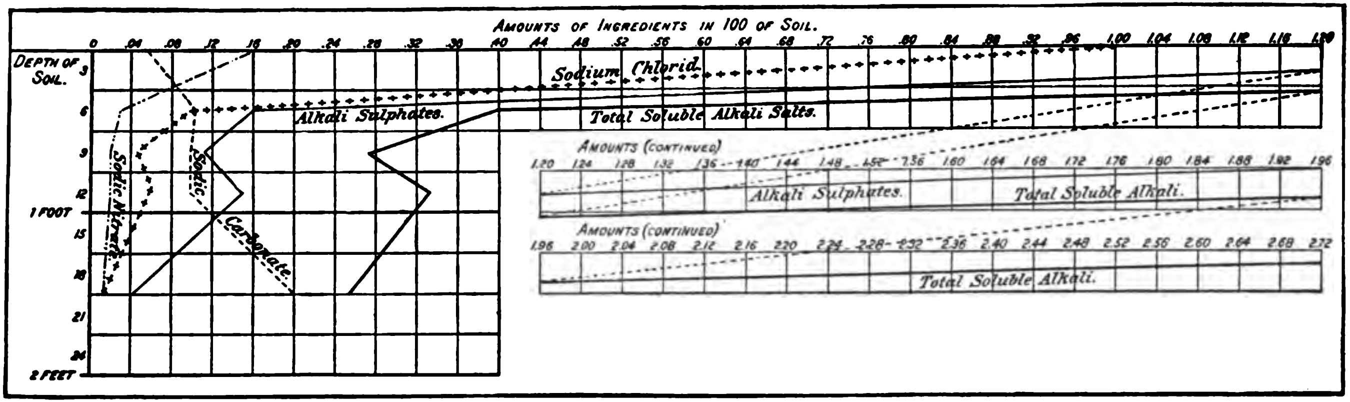

FIG 63.— Diagram showing amounts and composition of alkali salts at various depths in alkali soil, on which barley would not grow. Taken September, 1894. Tulare Experiment Sub-station, California.

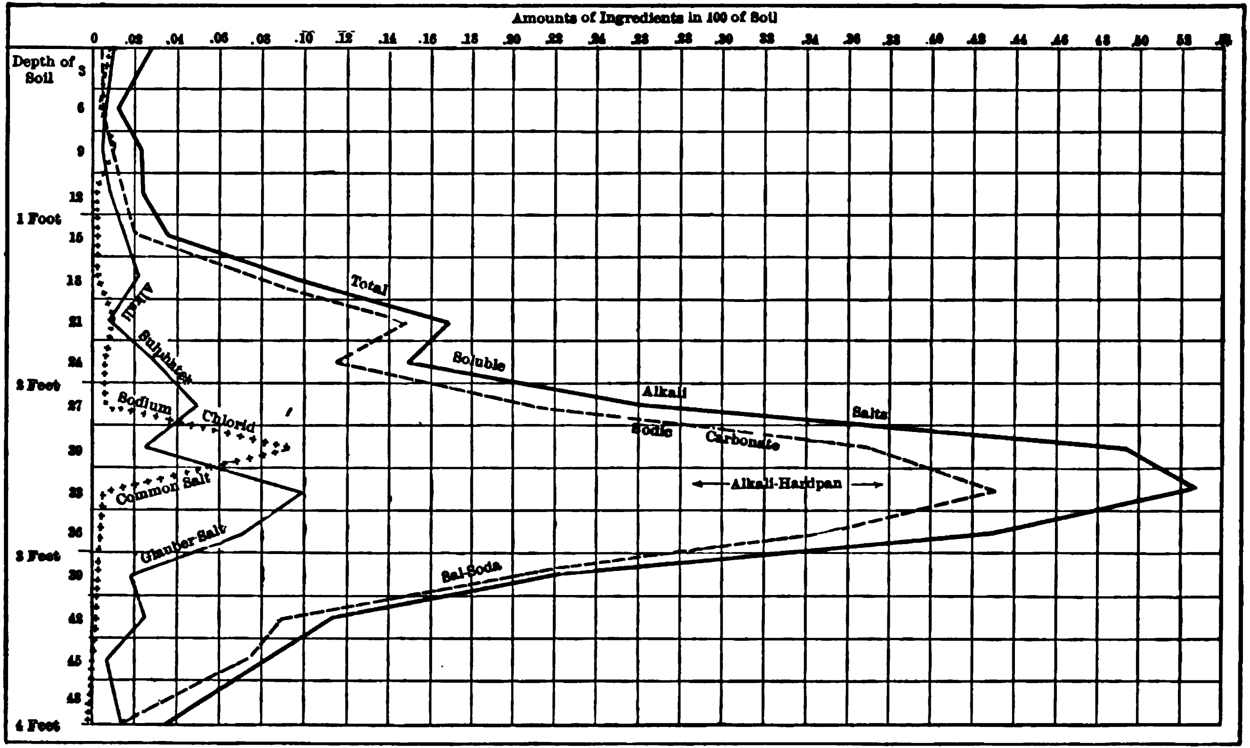

FIG. 64.—Diagram showing amounts and composition of alkali salts at various depths in black alkali land, covered with native vegetation. Taken March, 1895. Tulare Experiment Sub-Station, California.

It is thus that the luxuriant vegetation of the San Joaquin plains, dotted with occasional alkali spots, is maintained; the spots themselves being almost always depressions in which the rain water may gather, and where, in consequence of the increased evaporation, the noxious salts have risen to the surface and render impossible all but the most resistant saline growth; particularly when, in consequence of maceration and fermentation in the soil, the formation of carbonate of soda has caused the surface to sink and become almost water-tight.

Upward Translocation from Irrigation.—Fig. 65 shows the corresponding profile of the same soil after several years' irrigation. The upward movement of the salts is clearly seen by comparison with the previous figure; and the surface soil has become so charged with salts that the seeds of culture plants refuse to germinate.

Ten feet from this bare alkali ground, on which barley had refused to grow, a crop of barley four feet high was harvested the same year, without irrigation. Investigation proved that here the condition of the soil was intermediate between the two preceding diagrams. The irrigation water had dissolved the alkali of the subsoil, and the more abundant evaporation had brought it nearer the surface; but the shading by the barley crop and the evaporation of the moisture through its roots and leaves had prevented the salts from reaching the surface in such amounts as to injure the crop, although the tendency to rise was clearly shown. By the use of gypsum, moreover, the injuriousness of the alkali had been somewhat diminished.

The same season, grain crops were almost a failure on alkali-free land in the same region; and in connection with this result it should be noted as a general fact that alkali lands always retain a certain amount of moisture perceptible to the hand during the dry season, and that *this moisture can be utilized by crops;* so that at times when crops fail on non-alkaline land, good ones are obtained where a slight taint of alkali exists in the soil. Actual determinations showed that while a sample of alkali soil containing .54% of salts absorbed 12.3% of moisture from moist air, the same soil when leached absorbed only 2.5% —a figure corresponding to that of sandy upland loams.

Alkali in Sandy Lands.—In *very* sandy lands, and particularly when the alkali is " white " only, the tendency to accumu-

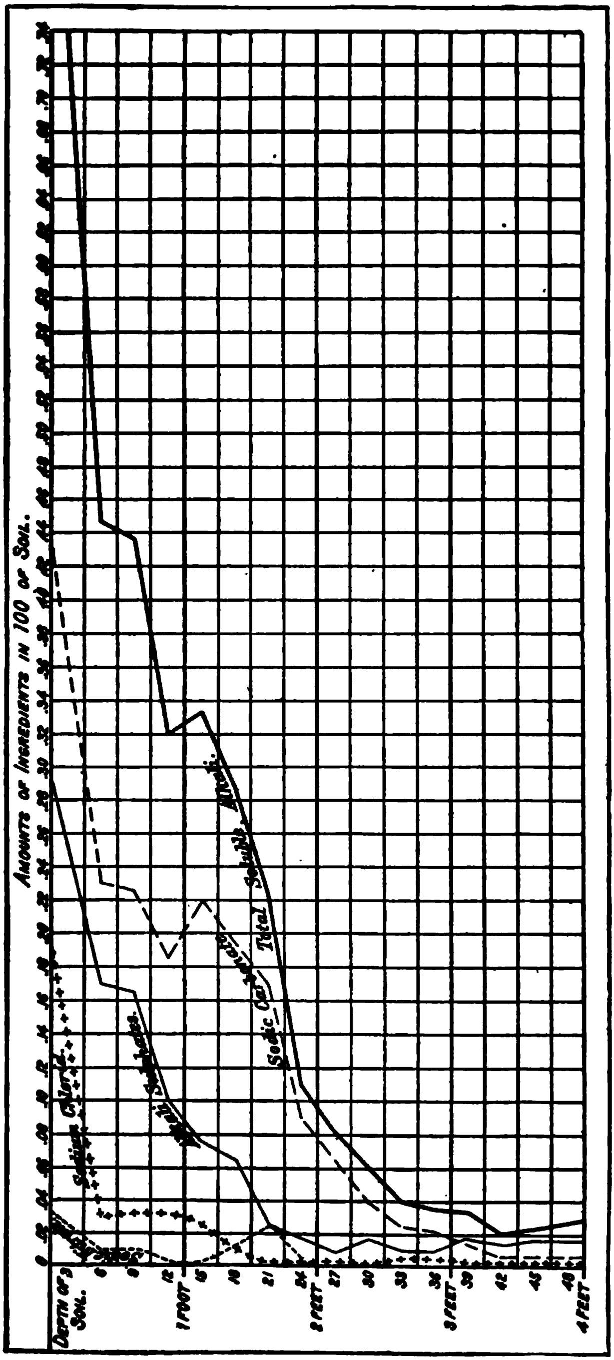

Fig. 65.—Diagram showing amounts and composition of alkali salts at various depths in bare alkali land, where barley would not grow; irrigated. Taken September, 1894. Tulare Experiment Substation, California.

lation near the surface is much less, even under irrigation. In the natural condition the salts are in such cases often found quite evenly distributed through soil columns of four feet, and even more. This is an additional cause of the lesser injuriousness of "white alkali." An illustration of the distribution of the salts in very sandy lands, from the Tulare substation, is given in Fig. 66. Here we see that the maximum is not *at*, but some distance below the surface, the entire saline mass is

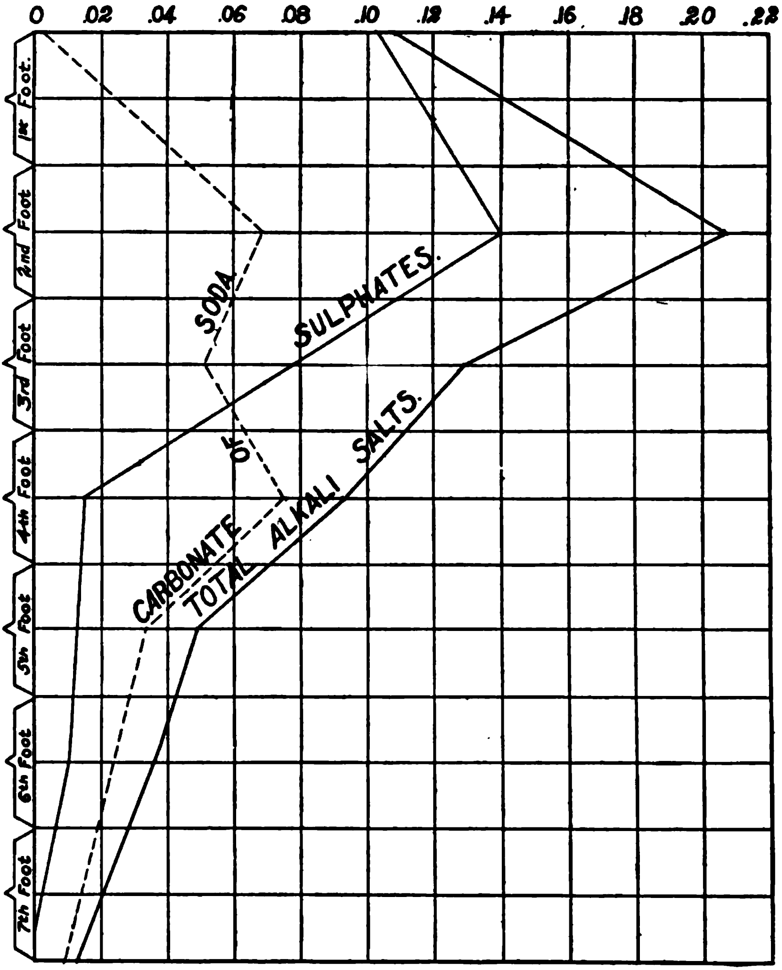

FIG. 66.—Distribution of Alkali Salts in Sandy Lands.

lower down than in the more clayey loam of the same locality, and is more widely distributed in depth.

Distribution of Alkali Salts in Heavy Lands.—The mode of distribution of alkali salts in the heavier, close-grained soil of the Chino experimental tract in southern California, is illustrated in Fig. 67. This land is permanently moist, from a water-table ranging from five to seven feet below the surface in ordinary years. There is therefore no opportunity for the formation of "alkali hardpan" as in the case of the Tulare soil; the salts always remain rather near the surface, viz. within twelve to fifteen inches. But being in much smaller average amounts than at Tulare (an average of about 5300 lbs. per acre), quite a copious natural vegetation of grasses, sunflowers, and "yerba mansa" covered the whole surface, save in a few low spots.

A similar mode of distribution of the salts is found in the still more clayey "black adobe" lands of the Great Valley of California. The scanty rains cannot penetrate these soils to any great depth, so that evaporation will soon bring the salts carried by them back to within a short distance of the surface. Their accumulation there is frequently indicated by the entire absence of any but the most resistant alkali weeds, even though the total of salts in the land may not be very great.

Salton Basin.—A peculiar state of things is illustrated in the Salton Basin, which represents what was at one time the head of the Gulf of California, and at the lowest point of which, 268 feet below sea level, there now lies a large deposit of rock salt. It has been cut off from the present Gulf by the delta deposits of the Colorado river, which now, however, overflows into the Basin at times of extreme high water. Although appearing level to the eye, the general slope of the country is to the lowest point of the former sea-bottom.

The region, now in progress of settlement by means of irrigation water brought from the river near Yuma, was investigated with respect to its alkali conditions in 1900 (Bulletin No. 140, Calif. Agric. Expt. Sta). The annexed diagram 68 shows the distribution of the salts to a depth of 21 feet. It will be noted that here also the alkali content becomes insignificant at 4 feet depth, but increases again to a second maximum at about 15 feet, below which there is a second decrease;

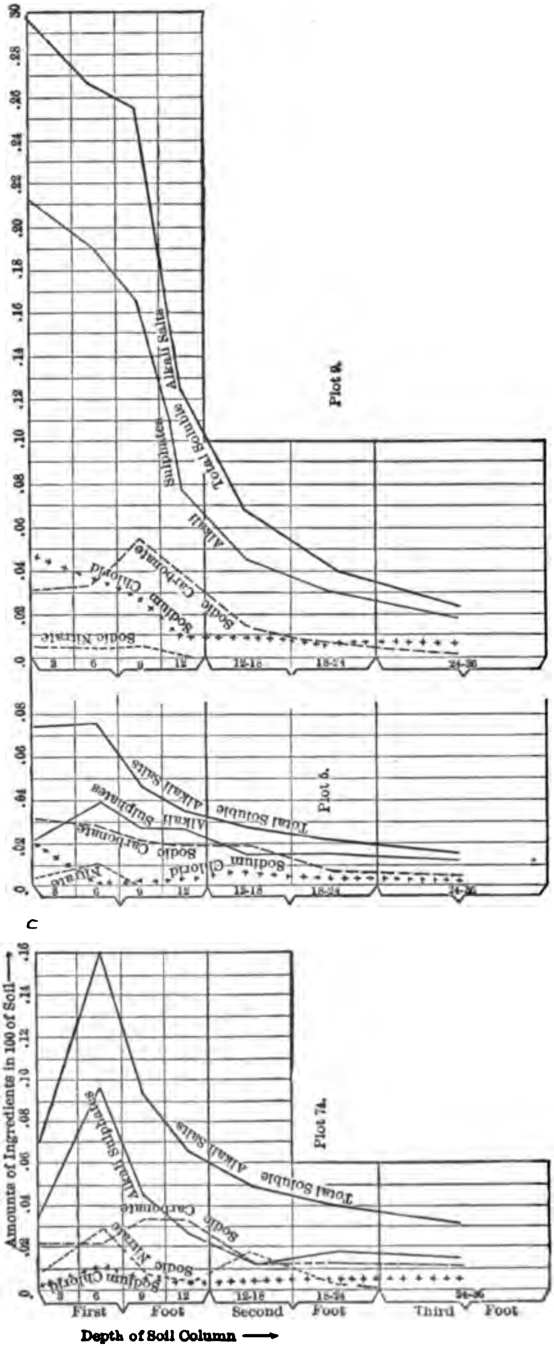

FIG. 67.—Amounts and composition of alkali salts at various depths and points in the ten-acre tract at the southern California Experiment Station; taken last week in April, 1895.

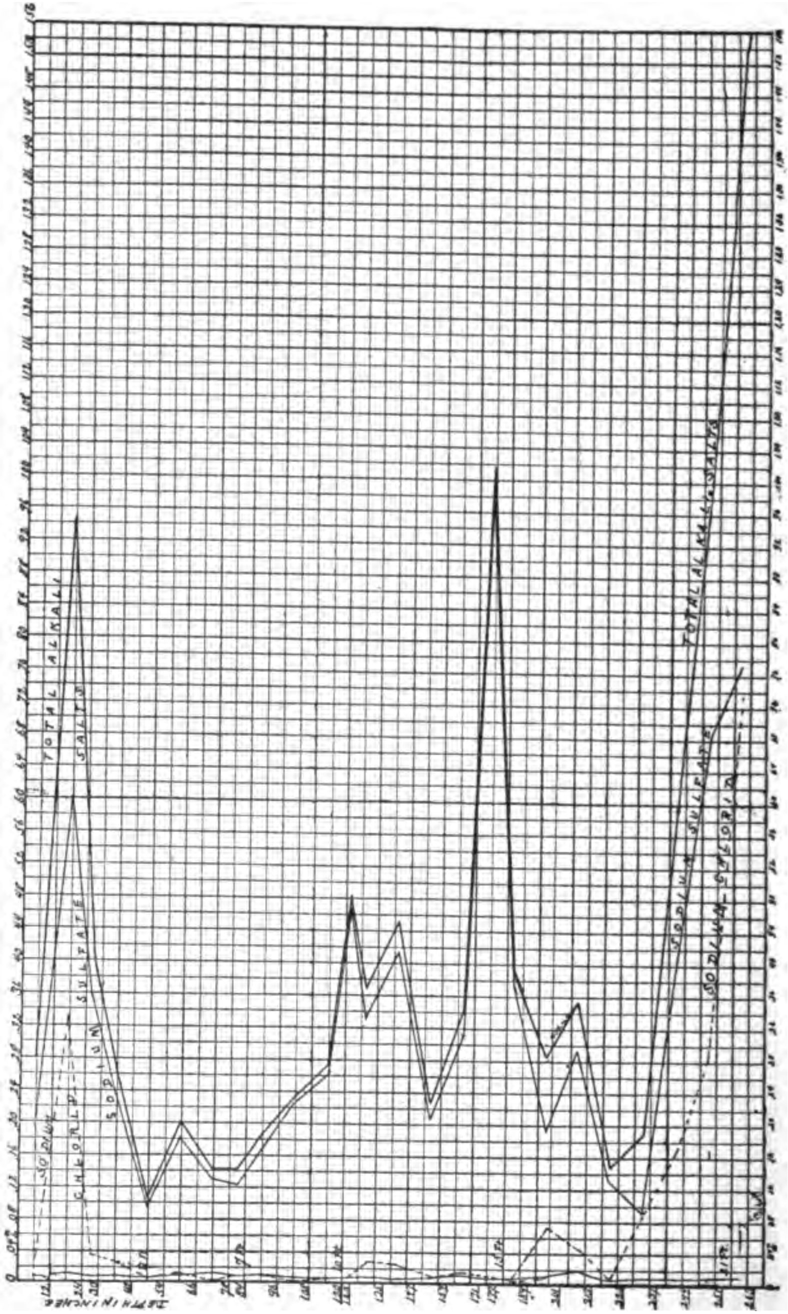

FIG. 68.—Graphic illustration of distribution of salts in Salton River section, California.

below this, at 20 feet, there is a final very heavy increase, not only of the total salts but especially of common salt, which evidently represents the drainage toward the salt deposit. Above this level there is a very remarkable predominance of Glauber's salt (sodium sulfate), also observable elsewhere, *e. g.* near White Plains, Nev., whose name is derived from the copious surface accumulation of the sulfate. It seems as though this must have been formed in some way from the common salt.

Horizontal Distribution of Alkali Salts in Arid Lands.—The constant occurrence of "alkali spots" in arid lands shows at once the great inequality of horizontal distribution of alkali impregnation. This is as prominent in level lands as on slopes, and in extremely arid regions it is mostly not possible to recognize even very considerable differences without close examination. Thus in lands appearing exactly alike on the surface, on the edge of the Salton basin in California, on the same forty acre 1.4% (56,000 pounds per acre) was found in the surface four feet at one point, and a hundred yards away, 12.5% (500,000 pounds). The mapping of alkali lands is therefore somewhat precarious unless carried into great detail. Moreover, it has been found that the location of the salts changes from year to year, especially in irrigated land, as might be expected. Those cultivating alkali lands have therefore to exercise constant watchfulness, unless the salts have been definitively eliminated by underdrainage over a considerable area; as merely local operations may be rendered ineffectual by the migration of the salts from neighboring tracts not reclaimed.

Alkali in Hill Lands.—As a rule, hill lands themselves are remarkably free from alkali, even in the arid regions; except when water is gathered in depressions, where strongly saline waters may be found in Washington, Montana and elsewhere. But on level plateau lands, where drainage is slow or imperfect, alkali appears as freely as it does in the same regions in the stream bottoms. In the latter the leachings and seepage of the uplands naturally causes a concentration of the salts, and thus we find alkali salts incrusting the surface in the valleys of the streams, as *e. g.*, that of the Yellowstone, Musselshell, Judith, Yakima and others in the north, and of Green river, Platte, Pecos, and Rio Grande farther south; as well as in numerous valleys of central and southern California.

Usar Lands of India.—These lands have been investigated first by the "Reh Commission" appointed to investigate the causes of the deterioration of lands in the Aligarh district (south of Delhi, between the Ganges and Jumna rivers), in 1876. The occasion of this appointment was the appearance of "reh" (alkali salts) in a region which had previously been free from them.[1] Subsequently, a more elaborate investigation of the subject was made by Dr. J. W. Leather, Agricultural Chemist to the Government of India.[2] From these documents it appears that "usar lands" exist largely not only in the Northwestern Provinces and Oudh, but also in the Panjab, especially on the lands bordering the Chenab river; likewise to a slight extent in the Bombay presidency. Leather's investigation shows that not all the lands designated by the natives as *usar* contain soluble salts in injurious amounts, some being simply lands having very hard, clayey soils difficult to till with the imperfect methods employed. Yet the general phenomena of the true "reh" lands are practically identical with those of the American alkali lands, including also the calcareous hardpan, there called *kankar.* Owing probably to the long cultivation of the Indian lands (mostly under irrigation), the salts are there at their maximum in the first foot, decreasing as depth increases. It is noteworthy also that in the majority of cases the predominant salt is carbonate of soda or black alkali, which there as in California renders the lands impervious to water until treated with gypsum. This fact accounts for the popular use of the same name for non-saline impervious clay soils, and the alkali or reh lands proper.

We have an entirely analogous case in the "Szek" lands of the Hungarian plain, some of which are simply poor refractory soils containing a trace of soluble salts; while lower down in the valley of the Theiss we find genuine alkali lands, both black and white, which have long furnished carbonate of soda for local use and commerce. In this case, however, the alkali salts seen to come largely, in some cases wholly, from underlying saline clays whose salts in coming to the surface suffer

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[1] An abstract of the report of this commission is given in the Report of the California Experiment Station for 1890.

[2] See Agricultural Ledger, 1897, No. 13; ibid. 1901, No. 13.

precisely the same transformations experienced in California and India, in presence of calcic carbonate (see below, p. 450 ff).

The accounts given by v. Middendorff of the nature and occurrence of alkali lands in Turkestan (Ferghana) agree entirely with those given above for California and India; as do also the investigations made by other Russian observers on the saline lands of the steppes of European Russia.

COMPOSITION AND QUANTITY OF ALKALI SALTS.

Black and White Alkali.—Broadly speaking, the world over alkali salts consist mainly of three chief ingredients, already mentioned, namely, common salt, Glauber's salt (sulfate of soda), and salsoda or carbonate[1] of soda. The latter causes what is popularly known as "black alkali," from the black spots of puddles seen on the surface of lands tainted with it, owing to the dissolution of the soil humus;[2] while the other salts, often together with Epsom salt and bittern (Magnesium chlorid), constitute "white alkali," which is known to be very much milder in its effect on plants than the black. In most cases all three are present, and all may be considered as practically valueless, or noxious, to plant growth.

Nutritive Salts in Alkali.—With them, however, there are almost always associated, in varying amounts, sulfate of pot-

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[1] In this designation are included, in this volume, both the normal (mono-) carbonate and the two other compounds, the bi- or hydrocarbonate and the intermediate (so-called sesqui-) compound or trona; all of which are commonly present simultaneously, but in utterly indefinite relative proportions, varying from day to day and from inch to inch of depth, inasmuch as their continued existence depends upon the greater or less formation of carbonic acid in the soil, and the access of air. Hence their separate quantitative determination at any one time is of little practical interest. All naturally occurring carbonate of soda contains, and sometimes consists of, these "super-carbonates," according to the greater or less exposure to air and solar heat. They are much milder in their action on plants than the mono-carbonate, which unfortunately, in the nature of the case, always predominates near the surface, and thus injures the root-crown.

[2] A wholly different kind of "black alkali" exists in some regions, especially in the delta lands of the Colorado of the West and in the Pecos and Rio Grande country in New Mexico. In these cases the dark tint is due, not to a humic solution, but simply to moisture, which is tenaciously retained by the chlorids of calcium and magnesium impregnating the land, thus contrasting strongly with the gray tint of the general dry soil.

	EUROPE.		ASIA.								AFRICA.			
	HUNGARIAN PLAIN "SZEKSO."		ARALO-CASPIAN PLAIN. SALINE CRUSTS.			ADEN. "HURKA" "KARA."	INDIA. "REH."				EGYPT.			
	Debreczin.	Kalocsa.						Gursikar, Aligarh, 6 feet.	Jellalabad, Panjab, 1.5 feet.	Bayamati (Regur), Deccan, 2 feet.	Trona, (Commercial.)		Alkali L. Abukir.	Fezzan Trona, (Commercial.)
Potassium Sulfate (K_2SO_4)	......	......	......	......	......	......	11.1	......	......	......	......	......	6.49	......
Sodium Sulfate (Na_2SO_4)	.2	1.6	10.4	18.2	15.5	......	7.0	15.5	58.5	2.3	23.6	38.3	.82	0.6
Sodium Carbonate (Na_2CO_3)	48.1	92.5	14.7	12.1	69.0	67.2	79.0	56.9	22.9	....	28.2	47.7	1.13	98.7
Sodium Chlorid (NaCl)	51.7	4.4	74.6	69.7	15.5	32.8	2.9	27.6	18.6	97.7	48.2	14.0	89.74	.7
Sodium Phosphate (Na_3PO_4)	......	1.5	......	......	......	......	......	......	......	......	......	......	......	......
Calcium Chlorid	......	......	......	... ..	......	......	......	......	......	......	......	......	1.82	......
Magnesium Chlorid ($MgCl_2$)														
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.00	100.0

	CALIFORNIA.									WASHINGTON.			
	Merced Falls.	Overhiser, San Joaquin Co.	Tulare County.		Kern Island.	Mojave Plateau.	Hunts, near San Bernardino.	Westminster, near Santa Ana.	Imperial.	Yakima Co. on Atahnam Creek.	Kittitas Valley.	Whitman Co., Lake Creek.	Spokane Co., Cottonwood Springs.
			Visalia.	Expt. Station. Tulare.									
Potassium Chlorid, KCl	......	......	......	......	......	......	......	......	1.15	3.90	0.16	4.53	6.27
Potassium Sulfate, K_2SO_4	.. ...	......	20.23	3.95	10.13	0.92	5.31	20.62	......	18.44	15.17	15.90	......
Potassium Carbonate. K_2CO_3	......	......	......	......	......	......	......	6.59	......	......	......	......	......
Sodium Sulfate, Na_2SO_4	4.67	13.00	......	25.28	88.42	43.34	66.08	......	......	......	......	......	......
Sodium Nitrate, $NaNO_3$	12.98	......	......	19.78	......	......	......	......	8.21	75.61	80.36	77.10	87.14
Sodium Carbonate, Na_2CO_3	75.95	52.22	65.72	32.58	0.42	15.38	15.85	62.22	.58	0.52	1.76	1.34	4.03
Sodium Chlorid, NaCl	1.46	33.00	3.98	14.75	0.51	39.34	11.47	10.57	31.82	1.53	2.55	1.13	2.56
Sodium Phosphate, HNa_2PO_4	4.94	1.78	8.42	2.25	......	1.02	......	......	......	......	......	......	......
Magnesium Sulfate, $MgSO_4$	......	......	1.65	......	0.52	......	0.59	......	......	......	......	......	......
Calcium Chlorid	......	......	......	... ..	......	......	......	......	58.42	......	......	......	......
Magnesium Chlorid	......	......	......	......	......	......	......	......	2.81	......	......	......	......
Ammonium Carbonate, NH_4CO_3	......	......	......	1.41	......	......	......	......	......	......	......	......	......
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	MONTANA.					NEVADA.			WYOMING.			
	UPPER MISSOURI VALLEY.								SWEET WATER VALLEY.		LARAMIE FARM.	
	Upper Missouri Valley, near Centerville.	Prickly Pear Plain, Helena.	Ford on Sun River.	Fort Benton.	Robert's Creek, Musselshell Valley.	NEAR RENO.		Churchill County.	Independence. Rock Lake.	Saint Mary's Station.	Alkali.	Waste Irrigation Water.
Potassium Sulfate, K_2SO_4	2.37	3.07	1.77	8.59	3.07	......	......	......	......	......	......	......
Sodium Sulfate, Na_2SO_4	56.54	43.38	83.35	47.10	76.79	52.15	80.30	0.55	73.17	88.93	59.29	41.19
Sodium Nitrate, $NaNO_3$	9.39	......	......	......	......	......	......	......	......	......	......	......
Sodium Carbonate, Na_2CO_3	......	......	......	.71	13.99	45.37	15.24	96.78	22.98	......	......	......
Sodium Chlorid, NaCl	27.47	14.60	0.91	.18	6.15	2.48	4.46	2.67	3.85	11.63	17.01	2.18
Magnesium Sulfate, $MgSO_4$	4.23	38.94	13.97	43.42	......	......	......	......	......	......	23.70	43.82
Potassium Chlorid, KCl	......	.....	......	......	......	......	......	......	......	......	......	12.81
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

	COLORADO.				NEW MEXICO.				
					PECOS VALLEY.				
					ROSWELL REGION.			CARLSBAD REGION.	
	Near Denver.	Grand Junction.	Rocky Ford.	Rocky Ford.	Bremond.	Michelet.	Roswell.	Carlsbad.	Delaware River.
Potassium Sulfate, K_2SO_4	......	......	0.10	13.74	......	......	......	......	......
Sodium Sulfate, Na_2SO_4	93.40	56.05	62.54	17.36	54.62	2.62	67.46	35.16	37.11
Sodium Carbonate, Na_2CO_3	......	18.97	2.08	5.53	......	.....	......	......	......
Sodium Chlorid, NaCl	6.60	24.98	3.86	11.53	51.60	65.16	10.00	26.88	34.31
Magnesium Sulfate, $MgSO_4$	......	......	31.42	44.43	13.79	32.22	22.54	38.06	28.58
Magnesium Chlorid, $MgCl_2$	......	......	......	5.76	......	......	......	......	......
Magnesium Phosphate	......	......	......	1.65	......	......	......	......	......
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

ash, phosphate of soda, and nitrate of soda, representing the three elements—potassium, phosphorus, and nitrogen—upon the presence of which in the soil in available form, the welfare of our crops so essentially depends, and which we aim to supply in fertilizers. The potash salt is usually present to the extent of from 5 to 20 per cent of the total salts; phosphate, from a fraction of one to as much as 4 percent; the nitrate from a fraction of one to as much as 20 percent. In black alkali the nitrate is usually low, the phosphate high; in the white, the reverse is true. Both relations are readily intelligible from a chemical and bacteriological point of view.

Estimation of Total Alkali in Land.—The investigations detailed above having shown that in California at least, outside of the axes of valleys no practically important amount of alkali salts is usually found at a depth exceeding four feet, it became possible to determine approximately the amounts of salts that would have to be dealt with when irrigation and evaporation should bring the entire amount to or near the surface; a necessary prerequisite to the determination of possible cultures. While, as already shown, the salts occur lower down in very sandy lands, yet the diagram on p. 435 shows that even then, an estimate on this basis would not be very wide of the truth. It is at least probable that the same is measurably true of level alkali lands elsewhere, when not underlaid by geological deposits impregnated with salts.

The total amount of these salts ordinarily found in alkali lands (*i. e.* in such as in the dry season show saline efflorescences on the surface) is from about one tenth of one per cent to as much as three per cent of the weight of the soil, taken to the depth of four feet. The percentage of salts having been determined in samples representing a tract, it becomes easy to calculate, approximately, the total amounts of each salt present per acre, on the basis of the weight of the soil per acre foot. For the soils of the arid region, such weight will usually range from three million five hundred thousand to four million pounds per acre-foot; the latter being the most usual figure, of which it may be conveniently remembered, that forty thousand pounds represent 1 per cent. We are thus enabled to estimate *e. g.* the amount of gypsum required to neutralize the carbonate of soda in the salts, or the amounts of valuable nutritive ingredients—potash, phosphoric acid and nitrates—present in the land in the water-soluble form.

As has been shown in the preceding discussion, the analysis at the surface foot alone, which has frequently been alone made, gives no definite clew whatever to the *total* amounts of salts to be controlled. A *full* estimate is of special importance in enabling us to forecast what culture plants are likely to succeed on a given tract, by reference to the table of "tolerances" given below (chapter 23, page 467).

Composition of Alkali Soils as a Whole.—As may be imagined, the presence of the alkali salts finds expression in the analytical statement of their composition, although not to the extent usually anticipated from their superficial aspect. The table annexed gives the composition of fourteen alkali soils, taken to the depth of one foot, at times when there was no visible accumulation of salts on the surface. The averages of the several ingredients determined are given in the fifteenth column, and a comparison of its figures with those of the general table on page 377 of chapter 20 will show some marked characteristics. We find the average potash-content to be but little less than twice as great as in the general average for the state of California; in the case of lime the ratio is nearly as one to three, in the case of magnesia nearly one to two; in that of phosphoric acid, one to two and a half, of which in the presence of carbonate of soda an unusually large proportion is in a readily soluble, often in the water-soluble, condition (see preceding table).

The usual proportion of soda, of one-fourth to one-half of the amount of potash, is changed to one-half or three-fourths; in the case of the strongest alkali lands soda may equal or even exceed the potash content. As the latter, however, is invariably high to very high, it does not happen as frequently as might be supposed that the soda content exceeds that of potash as shown by the usual method of soil-extraction with water.

That the *potash* percentage should always be high in alkali lands, is hardly surprising when it is considered that the continued presence of the salts resulting from rock decomposition affords opportunity for the full exercise of the preference with which potash is known to be retained

COMPOSITION OF ALKALI SOILS AS A WHOLE.

COLLECTION NUMBER.	White Ash, Fresno. —704—	Wire Grass, Visalia. —585—	Plains, Cross Creek, Tulare. —573—	Salt Grass, B. V. Slough. —700—	Tulare Lake Alluvium, Tulare County. —891—	—893—	—77—
Coarse Materials > 0.55 mm	....	14.29	1.50	....	....	....	4.10
Fine Earth	....	85.71	98.50	....	all	all	95.90
CHEMICAL ANALYSIS OF FINE EARTH.							
Insoluble matter	85.87 } 88.58	66.47 } 71.42	66.08 } 69.46	87.06 } 89.04	54.71 } 64.55	56.92 } 67.15	67.34
Soluble silica	2.71	4.95	3.38	1.98	9.84	10.13	....
Potash (K_2O)	.34	1.22	1.82	.49	2.02	1.65	1.05
Soda (Na_2O)	.25	.68	.44	.35	2.73	.54	.84
Lime (CaO)	1.16	3.04	4.31	1.20	2.46	2.96	6.51
Magnesia MgO)	.50	.09	1.59	1.07	2.93	3.12	3.69
Bro. ox. of Manganese (Mn_3O_4)	.03	.03	.08	.03	.03	.04	.04
Peroxid of Iron (Fe_2O_3)	3.28	5.82	6.04	5.82	7.46	6.73	5.05
Alumina (Al_2O_3)	3.22	7.14	8.69	.17	11.50	10.35	7.97
Phosphoric acid (P_2O_5)	.10	.24	.74	.08	.11	.16	.32
Sulfuric acid (SO_3)	.12	.66	.26	.13	.01	.01	.08
Carbonic acid (CO_2)	......	2.55	2.53	......	1.81	.93	4.42
Water and organic matter	1.79	7.09	4.15	1.13	4.34	5.77	3.71
Total	99.37	99.97	99.51	99.51	99.95	99.92	101.29
Chlorin, per cent							
Humus	.60	1.00	1.00	.17	......	.88	.47
" Ash	.35	.84	.74	.20	......	1.03	2.18
" Nitrogen, per cent. in Humus	18.66	14.10	......	......	......	......	9.37
" " , per cent. in soil	.11	.15	......	......	......	......	.05
Hygroscopic Moisture	2.22	8.53	8.74	2.16	10.50	8.6	
absorbed at °C	......	......	14°	15°	10°	10°	

COMPOSITION OF ALKALI SOILS AS A WHOLE.

COLLECTION NUMBER	Tulare Substation. —1159—	Ten-acre tract. Chino, S.B.Co. —1284—	Carisa Plain, S. L. Obispo. —1423—	Perris Valley, Jacinto river, Jacinto Plain, Riverside Co. —1758—	Perris Valley, Jacinto river, Jacinto Plain, Riverside Co. —1760.—	Sand. Coachella, Riverside Co. —2471—	Silt, Imperial, S. Diego Co. —2325—	Average of 14 soils.
Coarse Materials > 0.55m.m.	1.96	1.00	9.00	7.50	3.50	......	......	
Fine Earth	98.04	99.00	91.00	92.50	96.50	all	all	
CHEMICAL ANALYSIS OF FINE EARTH.								
Insoluble matter	72.98 } 73.58	62.62 } 70.92	57.33 } 69.48	41.59 } 63.13	35.20 } 58.95	66.17 } 77.54	62.67 } 73.60	63.08 } 72.19
Soluble silica	6.60	18.30	12.15	21.54	23.75	11.37	10.93	9.11
Potash (K_2O)	1.20	.95	1.22	1.37	1.16	1.26	.74	1.17
Soda (Na_2O)	.52	.50	.77	1.97	.96	.37	.29	.78
Lime (CaO)	1.86	5.07	4.46	4.23	8.00	2.71	3.75	3.71
Magnesia (MgO)	1.81	.84	3.12	3.80	5.69	2.20	1.68	2.29
Br. ox. of Manganese (Mn_3O_4)	.08	.06	.01	.03	.04	.05	.01	.04
Peroxid of Iron (Fe_2O_3)	6.86	6.43	7.65	9.65	7.33	6.43	3.71	6.30
Alumina (Al_2O_3)	5.66	4.88	0.16	7.26	6.29	5.53	4.26	6.65
Phosphoric acid (P_2O_5)	.10	.21	.43	.23	.28	.21	.22	.20
Sulfuric acid (SO_3)	.03	.06	.06	.34	.21	.08	.36	.17
Carbonic acid (CO_2)	....	3.76	....	4.19	6.49	1.05	2.32	2.14
Water and organic matter	2.54	1.02	2.63	2.89	4.71	2.55	8.93	4.19
Total	100.24	99.70	99.99	99.81	99.84	99.98	99.87	
Chlorin, per cent				.12	Trace.			
Humus, per cent	.37	1.99	1.39	.60	.91	.46	.65	.75
" Ash, per cent	.32	1.13	.95	.92	1.75	.42	.69	.82
" Nitrogen, per cent. in Humus	16.75	10.20	14.36	6.66	7.70	......	10.90	
" " , per cent. in soil	.06	.20	.06	.04	.07	......	.07	
Hygroscopic Moisture		5.81	8.46	9.43	8.85	2.64	2.98	5.63
absorbed at °C		15°	15°	15°	15°	15°	15°	15°

in soils by the formation of complex zeolitic silicates. In most cases the potash-percentage exceeds .75%, and rises as high as 2.0%; as is shown in the table.

This table exhibits also another standing characteristic of alkali soils, which is to be anticipated from the conditions of their formation; viz, high *lime-content,* which sometimes rises to the extent of marliness.

In *phosphates,* also, alkali soils are almost always high; and an unusually large proportion is found to be readily soluble.

In presence of much carbonate of soda, *nitrates* are usually scarce or altogether absent; while owing to the action of the alkaline solution upon the humus, ammonia salts, or even free (or carbonated and therefore readily dissociated and assimilated) *ammonia* may be present, so as to be perceptible to the senses by its odor in hot sunshine. But in the case of "white alkali," more especially of the sulphate in moderate amounts, nitrification is exceedingly active and nitrates may sometimes rise to as much as 20% of the soluble salts. As alkali spots are usually low in the central portion and therefore more moist than around the edges, we sometimes find ammonia salts in the middle of a spot, while nitrates are abundant along the margin of the same. These differences, first demonstrated by an investigation made by Colmore,[1] illustrate some of the reactions that are essentially concerned in the agricultural availability of alkali lands. A summary of Colmore's results is given in the table below.

Cross Section of an Alkali Spot.—The spot examined lies outside of Tulare, California, substation; it being late in the season, when the bulk of the salts is found near the surface, the samples were taken to the depth of one foot only, at points four feet apart, from the center out.

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[1] Report of the California Exp't St'n for 1892–94, p. 141.

AMOUNT AND COMPOSITION OF SALTS IN ALKALI SPOT FROM CENTER TO CIRCUMFERENCE, 4 FEET APART, 1 FT. DEPTH.

Mineral Salts.	1 Center of spot.	2 Four feet.	3 Eight feet.	4 Twelve feet.	5 Outer margin.
Potassium sulfate	6.70	9.55	11.92	19.26	13.95
Sodium sulfate	19.84	12.85	23.72	23.97	16.96
Magnesium sulfate	3.07	.07	.95	2.05	8.29
Sodium chlorid	13.80	23.73	24.12	24.23	29.69
Sodium carbonate	50.72	50.96	37.55	35.49	29.94
Sodium phosphate	5.57	2.88	.87	?	1.04
Sodium nitrate	.30	?	.87	?	.13
Totals	100.00	100.00	100.00	100.00	100.00
Organic matter	30.00	24.80	19.48	23.36	20.31
Total soluble in soil	.78	.54	.70	.37	.34
Mineral salts	.38	.40	.54	.25	.23

While the table shows an obvious irregularity in some of the data at the eight-foot point, arising doubtless from an irregularity of surface or of texture overlooked in taking the samples, we find a very remarkable regularity of progression in the cases of potassium sulfate, sodium chlorid, sodium carbonate and sodium phosphate in the other four samples. The maxima of the "black alkali" and the soluble organic matter (humus) coincide, as does that of the phosphate; the total mineral salts at the outer margin are only a little over half of what is found at the center. This is natural, as owing to the deflocculating effect of the black alkali, the center is nearly a foot lower than the margin. The lowering of the nitrate-content at the outer margin is obviously due to the luxuriant vegetation growing adjacent.

Reactions between the Carbonates, Chlorids and Sulfates of Alkalies and Earths. That a soluble earth-salt, such as the sulfate or chlorid of calcium, will react upon an alkaline carbonate solution so as to form an alkali sulfate, and *e.g.* lime carbonate, is well known; the neutralization of the sodic carbonate in the soil by means of gypsum, above referred to, is based upon this reaction. It is not so well known that the latter may be reversed, partly or wholly, by the presence of carbonic acid in the solution of the soil. Although observed as early as 1824 by Brandes, and again in 1859 by A. Müller, this reaction is not mentioned in textbooks and attracted no attention as a source of naturally occurring alkali carbonates which in the past have formed the basis of extensive commerce from the Orient, until in 1888, the writer together with Weber and later with Jaffa, investigated it quantitatively.[1] It was found that up to .75 grms. per liter, the entire amount of sodic sulfate present in solution is transformed into carbonate in presence of calcic carbonate, by a current of carbonic dioxid; but the amount so transformed does not continue to increase beyond about 4 grams per liter. A corresponding amount of calcic sulfate is formed. In the case of potassic sulfate, the transformation also occurs, proportionally to the molecular weight. This relation is shown in the subjoined diagram, which also shows in the curves on the left, the residual alkalinity left after evaporation and drying the residue at 100° C.

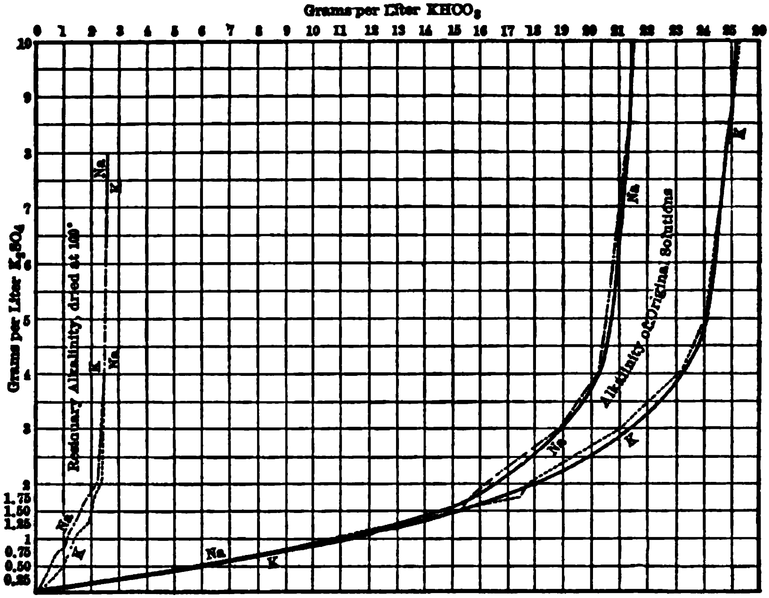

FIG. 69.—Progressive Transformation of Alkali Sulfates into Carbonates. (The figures along upper line represent tenths of one per cent.)

The corresponding reaction occurs also, of course, between sodium chlorid and calcium carbonate, but not to the same extent, because unlike the difficultly soluble gypsum, the reaction product is the very soluble calcium chlorid, the presence of which in the solution limits the reaction much sooner than when most of the decomposition product is thrown down in

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[1] Proc. Am. Soc. Agr. Sci., 1888; ibid., 1890; Rep. Cal. Expt. Sta., 1890, p. 100; Ber. Berlin, Chem. Ges., 1893; Am. Jour. Sci., August 1896.

the solid state. The calcium chlorid not uncommonly found in some alkali regions is undoubtedly the product of the above reaction.

As the saline solutions in the soil are mostly quite dilute, and calcic carbonate is always present, it follows that whenever under the influences which favor the oxidation of organic matter in the soil, and the activity of the plant roots, carbonic gas is formed somewhat copiously, alkali sulfates and chlorids present may be partially or wholly transformed into carbonates within the soil. As a matter of fact, it is found that this transformation occurs most readily in the moister portions of the soil and subsoil, and *invariably so when an alkali soil is "swamped" by excessive irrigation or rise of bottom water;* while the reaction is again reversed whenever free access of air reduces the carbonic dioxid below a certain point. It thus becomes intelligible why in the diagrams showing the distribution of the salts (this chapter pp. 431 and 432), we always find the sodic carbonate relatively *decreasing* as the surface is approached.

Thus, also, is explained the fact that sodium carbonate is formed more abundantly toward the center of the root system of alkali plants, such as the greasewood, beneath which the soil is always more abundantly charged with "black alkali" than is the surrounding earth.

Good aëration of the soil mass, then, is essential in maintaining the neutralization of the "black alkali" soils brought about by the use of gypsum (land plaster).

Inverse Ratios of Alkali Carbonates and Sulfates.—According to the above considerations, it is not surprising that we should often find an apparent inverse ratio between the alkali sulfates and carbonates in soils so closely adjacent that their salts must be presumed to be similar in composition. A striking example is shown in fig. 70, in which this inverse ratio becomes apparent four times in succession in one and the same soil profile. While this inference is plain on the face of the diagram, it is not quite easy to explain in detail how this alternation came about from the condition observed two months previously. Most probably it was caused by corresponding alternations of weather, in which short, warm spring showers alternated with similarly brief periods of drying north winds;

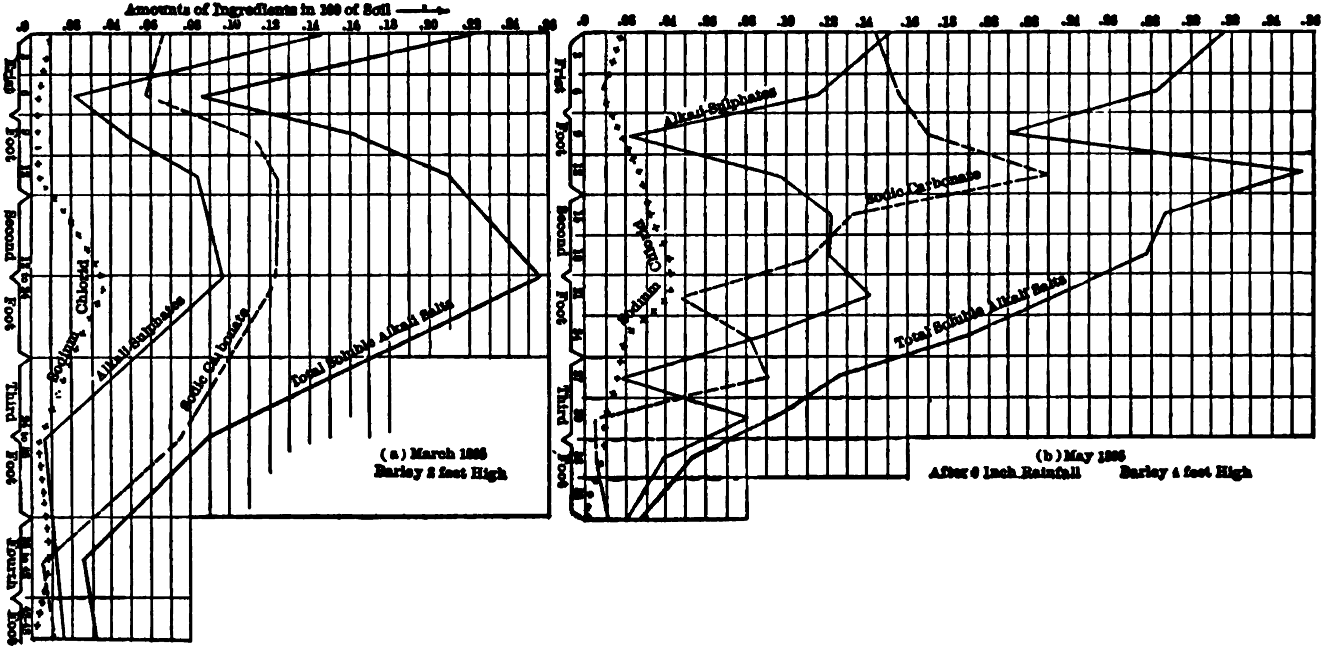

FIG. 70.—Amounts and Composition of Alkali Salts at various depths in partly reclaimed Alkali Land. Tulare Experiment Substation, California.
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the latter causing a reversal of the formation of sodic carbonate that had been induced by the former.

Exceptional Conditions.—While the phenomena of alkali lands as outlined above probably represent the vastly predominant conditions on level lands, yet there are exceptions due to surface conformation, and the local existence of sources of alkali salts outside of the soil itself. Such is the case where salts ooze out of strata cropping out on hillsides, as at some points in the San Joaquin Valley in California, and in parts of New Mexico, Colorado and Wyoming; also where, as in the Hungarian plain, saline clays underlie within reach of surface evaporation.

Again, it not infrequently happens that in sloping valleys or basins, where the central (lowest) portion receives the salts leached out of the soils of the adjacent slopes, we find belts of greater or less width in which the alkali impregnation may reach to the depth of ten or twelve feet, usually within more or less definite layers of calcareous hardpan, likewise the outcome of the leaching of the valley slopes. Such areas, however, are usually quite limited, and are at present scarcely reclaimable without excessive expenditure; the more as they are often underlaid by saline bottom water. In these cases the predominant saline ingredient is usually common salt, as might be expected and as is exemplified in the Great Salt Lake of Utah, in the Antelope and Perris Valleys, and in Salton basin in California; in the Yellowstone valley near Billings, Mont.[1] in the Aralo-Caspian desert, and at many other points.

Conclusions.—Summing up the conclusions from the foregoing facts and considerations, we find that—

(1) The amount of soluble salts in alkali lands is usually limited; they are not ordinarily supplied in indefinite quantities from the bottom-water below. These salts have mostly been formed by weathering in the soil-layer itself.

(2) The salts move up and down within the upper four or five feet of the soil and subsoil, following the movement of the moisture; descending in the rainy season to the limit of the annual moistening as a maximum, and then reascending or not, according as surface evaporation may demand. At the end of

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[1] Farmer's Bull. No. 88, U. S. Dept. Agr., 1899.

the dry season, in untilled irrigated land, practically the entire mass of salts may be within six or eight inches of the surface.

(3) The direct injury to vegetation[1] is caused largely within a few inches of the surface, by the corrosion of the bark, usually near the root crown. This corrosion is strongest when carbonate of soda (salsoda) forms a large proportion of the salts; the soda then also dissolves the vegetable mold and causes blackish spots in the soil, popularly known as black alkali.

(4) The injury caused by carbonate of soda is aggravated by its action in puddling the soil so as to cause it to lose its crumbly or flaky condition, rendering it almost or quite untillable and impervious. It also tends to form in the depths of the soil-layer a tough, impervious hardpan, which yields neither to plow, pick, nor crowbar. Its presence is easily ascertained by means of a pointed steel sounding-rod.

(5) While alkali lands share with other soils of the arid region the advantage of unusually high percentages of plant-food in the insoluble form, they also contain, alongside of the noxious salts, considerable amounts of water-soluble plant-food. When, therefore, the action of the noxious salts is done away with, they should be profusely and lastingly productive; particularly as they are always naturally somewhat moist in consequence of the attraction of moisture by the salts, and are therefore less liable to injury from drought than the same soils when free from alkali.

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[1] For a general statement and discussion of the physiological effects of saline solutions on plants, see chapter 26.

CHAPTER XXIII.

UTILIZATION AND RECLAMATION OF ALKALI LANDS.

Alkali-Resistant Crops.—The most obvious mode of utilizing alkali lands is to occupy them with crops not affected by the noxious salts. Unfortunately but few such crops of general utility have as yet been found for the stronger class of alkali lands. The question is always one of degree, which frequently cannot be decided without an actual determination of the amount and kind of salts to be dealt with, to which the crops can then be adapted in accordance with the greater or less sensitiveness of the several plants, as indicated in the table of tolerances given farther on. But aside from this, there are certain general measures and precautions which in any case will serve to mitigate the effect of the alkali salts. Foremost among these, and applicable everywhere, is the prevention of evaporation to the utmost extent possible.

Counteracting Evaporation.—Since evaporation of the soil-moisture at the surface is what brings the alkali to the level where the main injury to plants occurs, it is obvious that evaporation should be prevented as much as possible. This is the more important, as the saving of soil-moisture, and therefore of irrigation water, is attainable by the same means.

Three methods for this purpose are usually practiced, viz., shading, mulching, and the maintenance of loose tilth in the surface soil to such depth as may be required by the climatic conditions.

As to mulching, it is already well recognized in the alkali regions of California as an effective remedy in light cases. Fruit trees are frequently thus protected, particularly while young, after which their shade alone may (as in the case of low-trained orange trees) suffice to prevent injury. The same often happens in the case of low-trained vines, small-fruit, and vegetables. Sanding of the surface to the depth of several inches was among the first attempts in this direction; but the necessity of cultivation, involving the renewal of the sand each season, renders this a costly method. Straw, leaves, and manure have been more successfully used; but even these, unless employed for the purpose of fertilization, involve more expense and trouble than the simple *maintenance of very loose tilth of the surface soil throughout the dry season;* a remedy which, of course, is equally applicable to hoed field crops, and is in the case of some of these—*e. g.,* cotton—a necessary condition of cultural success everywhere. The wide prevalence of " light " soils in the arid regions, from causes inherent in the climate itself, renders this condition relatively easy of fulfilment.

Turning-under of Surface Alkali.—Aside, however, from the mere prevention of surface evaporation, another favorable condition is realized by this procedure, namely the commingling of the heavily salt-charged surface-layers with the relatively non-alkaline subsoil. Since in the arid regions the roots of all plants retire farther from the surface because of the deadly drought and heat of summer, it is usually possible to cultivate deeper than could safely be done with growing crops in humid climates. Yet even there, the maxim of " deep preparation and shallow cultivation " is put into practice with advantage, only changing the measurements of depth to correspond with the altered climatic conditions. Thus while in the humid States, three to four inches is the accepted standard of depth for summer cultivation to preserve moisture without injury to the roots, that depth must in the arid region frequently be doubled in order to be effective; and will even then scarcely touch a living root in orchards and vineyards, particularly in unmanured and unirrigated land.

A glance at fig. 63, chapt. 22, p. 431), will show the great advantage of extra-deep preparation in commingling the alkali salts accumulated near the surface with the lower soil-layers, diffusing the salts, say through twelve instead of six inches of soil mass. This will in very many cases suffice to render the growth of ordinary crops possible if, by subsequent frequent and thorough cultivation, surface evaporation, and with it the re-ascent of the salts to the surface, is prevented.

A striking example of the efficiency of this mode of procedure was observed at the Tulare substation, California, where a portion of a very bad alkali spot was trenched to the depth of two feet, throwing the surface soil to the bottom. The spot thus treated produced excellent wheat crops for two years—the time it took the alkali salts to reascend to the surface,

It should therefore be kept in mind that whatever else is done toward reclamation, *deep preparation and thorough cultivation* must be regarded as prime factors for the maintenance of production on alkali lands.

The Efficacy of Shading, already referred to, is strikingly illustrated in the case of some field crops which, when once established, will thrive on fairly strong alkali soil, provided that a good thick "stand" has once been obtained. This is notably true of the great forage crop of the arid region, alfalfa or lucern. Its seed is extremely sensitive to "black" alkali, and will decay in the ground unless protected against it by the use of gypsum in sowing. But when once a full stand has been obtained, the field may endure for many years without a sign of injury. Here two effects combine, viz., the shading, and the evaporation through the deep roots and abundant foliage, which alone prevents, in a large measure, the ascent of the moisture and salts to the surface. The case is then precisely parallel to that of the natural soil (see p. 432, chapter 22), except that, as irrigation is practiced in order to stimulate production, the sheet of alkali hardpan will be dissolved and its salts spread through the soil more evenly. The result is that so soon as the alfalfa is taken off the ground and the cultivation of other crops is attempted, an altogether unexpectedly large amount of alkali comes to the surface and greatly impedes, if it does not altogether prevent, the immediate planting of other crops. Shallow-rooted annual crops that give but little shade, like the cereals, while measurably impeding the rise of the salts during their growth (see fig. 70, page 452) frequently allow of enough rise after harvest to prevent reseeding the following season.

"Neutralizing" Black Alkali.—Since so little carbonate of soda as one-tenth of one per cent. may suffice to render some soils uncultivable, it frequently happens that its mere transformation into the sulfate is sufficient to remove all stress from alkali. Gypsum (land plaster) is the cheap and effective agent to bring about this transformation, provided water be also

present. The amount required per acre will, of course, vary with the amount of salts in the soil, all the way from a few hundred pounds to several tons in the case of strong alkali spots; but it is not usually necessary to add the entire quantity at once, provided that sufficient be used to neutralize the sodic carbonate near the surface, and enough time be allowed for the action to take place. In very wet soil, and when much gypsum is used, this may occur within a few days; in merely damp soils in the course of months; but usually the effect increases for years, as the salts rise from below.

The effect of gypsum on black-alkali land is often very striking, even to the eye. The blackish puddles and spots disappear, because the gypsum renders the dissolved humus insoluble and thus restores it to the soil. The latter soon loses its hard, puddled condition and crumbles and bulges into a loose mass, into which water now soaks freely, bringing up the previously depressed spots to the general level of the land. On the surface thus changed, seeds now germinate and grow without hindrance; and as the injury from alkali occurs at or near the surface, it is usually best to simply harrow in the plaster, leaving the water to carry it down in solution. Soluble phosphates present are decomposed so as to retain finely divided, but less soluble earth phosphates in the soil.

It must not be forgotten that this beneficial change may go backward if the land thus treated is permitted to be swamped by irrigation water or otherwise. Under the same conditions naturally white alkali may turn black (see above, chapter 22, p. 451). Of course, gypsum is of no benefit whatever on soils containing no " black " alkali, but only (" white ") Glauber's and common salt.

Removing the Salts from the Soil.—In case the amount of salts in the soil should be so great that even the change worked by gypsum is insufficient to render it available for useful crops, the only remedy left is to remove the salts, partially or wholly, at least from the *surface* of the land. Three chief methods are available for this purpose. One is to remove the salts, with more or less earth, from the surface at the end of the dry season, either by sweeping or by means of a horse scraper set so as to carry off a certain depth of soil. Thus sometimes in a single season one-third or one-half of the total salts may be got rid of, the loss of a few inches of surface soil being of little moment in the deep soils of the arid region. Another method affording partial relief is to flood the land for a sufficient length of time to carry the alkali three or more feet below the surface, then carefully preventing its reascent by suppressing evaporation (see this chapter, p. 455) as much as possible. The best of all, the final and universally efficient remedy, is to leach the alkali salt out of the soil into the country drainage; supplementing by irrigation water what is left undone by the deficient rainfall.

It is not practicable, as many suppose, to wash the salts off the surface by a rush of water, as they instantly soak into the ground at the first touch. Nor is there any certain relief from allowing the water to stand on the land and then drawing it off; in this case also the salts soak down ahead of the water, and the water standing on the surface remains almost unchanged. In very pervious soils and in the case of white alkali, the washing-out can often be accomplished without special provision for underdrainage, by leaving the water on the land sufficiently long. But the laying of regular underdrains greatly accelerates the work, and renders success certain.

Leaching-Down.—In advance of underdrainage, it is quite generally feasible, where the land has been leveled and diked for irrigation by surface flooding, to leach the salts out of the first three or four feet by continued flooding, thus taking them out of reach of the crop roots, or at all events giving the *seed* an opportunity to escape injury from alkali. This plan is especially effective in the case of alfalfa, the young seedlings of which are very sensitive, while the grown plant is rather resistant. In order to obtain this relief so as to know what is being accomplished, the farmer should ascertain beforehand how fast water will soak down in his ground;[1] for in heavy clay soils, and especially in those containing black alkali, the soakage is sometimes so slow that the upward diffusion of the salts keeps pace with the downward soakage; in which case nothing is accomplished by flooding, and underdrainage is the only remedy. But in most soils of the arid region flooding from three days to a week will remove the alkali beyond reach of the roots of ordinary crops. If subsequently irrigation is done

[1] See p. 242, Chap. 13.

by means of *deep* furrows, the alkali salts may be either kept at a low level continuously, or if the land be at all pervious, the alkali may ultimately be permanently leached out into the subdrainage by farther flooding. When the alkali has not accumulated near the surface to any great extent, irrigation by deep furrows may, alone, afford all the relief needed.

In the case illustrated by figures 71 and 72, irrigation by shallow furrows with water too strongly charged with salts had so far added to the natural alkali-content of the land that the lemon trees were being defoliated. Upon the advice of the California Station the deep-furrow system was adopted, and within two years the results were as shown in figure 72, the salts having been carried down and diluted so as to become harmless.

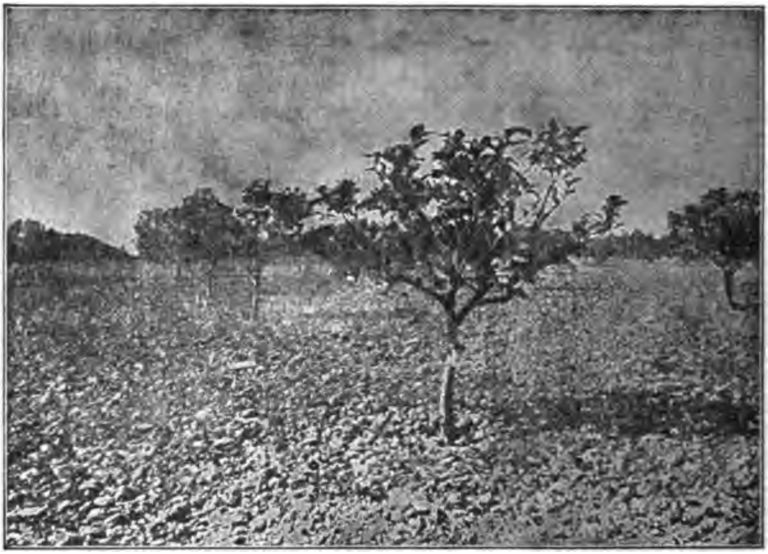

FIG. 71.—Lemon Orchard Affected by Alkali; Before Deep Irrigation.

Underdrainage the Final and Universal Remedy for Alkali.—When we underdrain an alkali soil, we adopt the very means by which the existence of alkali lands in the humid regions is wholly prevented; the leaching-out of the soluble salts formed in soil-weathering as fast as they are formed. The long and abundant experience had with underdrainage in reclaiming saline sea-coast lands, applies directly and cogently to alkali lands. It is the universal remedy for all the evils of alkali, and its only drawback is the first expense, and the necessity for obtaining an outlet for the drain waters, which cannot always be had on the owner's land. Hence it requires co-operation or legislation to render the great improvement of underdrainage feasible. Such legislation is well established in the old world, and has been enacted in several states even of the humid region. Where irrigation is practiced as a matter of necessity, underdrainage is a correlative necessity, both to avoid the evils of over-irrigation and to relieve the land of noxious alkali salts.

FIG. 72.—The Above Orchard after Alkali was Driven Down by Deep Irrigation, followed by Cultivation.

The drainage law now existing in California does not go farther than to authorize the formation of drainage districts, within which the necessary taxes may be levied; and there is some difficulty in securing popular action. But bitter experience will doubtless in time compel unanimity, such as now exists, *e. g.*, in Illinois, where drainage is not nearly so urgently needed as it is in the irrigation States.

Possible Injury to Land by Excessive Leaching.—It should not be forgotten, however, that excessive leaching of underdrained land by flooding is liable to injure the soil in two ways: first, by the removal of valuable soluble plant-food; and further, by rendering the land less retentive of moisture, such retention being favored by the presence of small amounts of alkali salts, not sufficient to injure crops. After the salts have been carried down to a sufficient depth to prevent injury to annual crops, and with proper subsequent attention to the prevention of surface evaporation, the flooding will not need to be repeated for several years. Thus in many soils excellent crops may be grown even in strong alkali land, pending the establishment of permanent drainage systems.

The importance of thoroughly washing the alkali deeply into the soil before the seed is planted, and keeping it there by proper means until the foliage of the plant shades the soil sufficiently to prevent the rise of moisture and alkali, is well illustrated in fields in the region of Bakersfield, Cal., where alfalfa is now growing in soils once heavily charged with alkali. From one of these fields samples of soil were taken where the alkali was supposed to be strongest beneath the alfalfa, and also from an adjoining untreated alkali spot, which was said to represent conditions before alfalfa was planted. The results are given in pounds per acre in four feet depth.

	Sulfate.	Carbonate.	Common Salt.	Total Alkali.
Alkali spot before alfalfa was planted.	60,120	720	175,840	236,680
Alfalfa field; alkali washed down....	14,400	...	1,040	18,640

Here the surface foot of the natural soil contained nearly 140,000 pounds of common salt, a prohibitory amount. Similar experience has been had near Yuma, Arizona.

Difficulty in Draining "Black" Alkali Lands.—An important exception to the efficacy of draining, however, occurs in the case of black alkali in most lands. In this case either the impervious hardpan or (in the case of actual alkali spots) the

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[1] Bull. 133, Cal. Expt. Sta., by R. H. Loughridge.

impenetrability of the surface soil itself will render even underdrains ineffective unless the salsoda and its effects on the soil are first destroyed by the use of gypsum, as above detailed. This is not only necessary in order to render drainage and leaching possible, but is also advisable in order to prevent the leaching-out of the valuable humus and soluble phosphates, which are rendered insoluble (but not unavailable to plants) by the action of the gypsum. Wherever black alkali is found in lands not very sandy, the application of gypsum should precede any other efforts toward reclamation. Trees and vines already planted may be temporarily protected from the worst effects of the black alkali by surrounding the trunks with gypsum or with earth abundantly mixed with it. Seeds may be similarly protected in sowing, and young plants in planting.

Swamping of Alkali Lands.—It should, however, be remembered that the *swamping* of alkali lands, whether of the white or black kind, is fatal not only to their present productiveness, but also, on account of the strong chemical action thus induced, greatly jeopardizes their future usefulness. Many costly investments in orchards and vineyards have thus been rendered unproductive, or have even become a total loss.

Reduction of Alkali by Cropping.—Another method for diminishing the amount of alkali in the soil is the cropping with plants that take up considerable amounts of salts. In taking them into cultivation, it is advisable to remove entirely from the land the salt growth that may naturally cover it, notably the greasewoods (*Sarcobatus, Allenrolfea*), with their heavy percentage of alkaline ash (12 to 20 per cent). Crop plants adapted to the same object are mentioned farther on. Such crops should also, of course, be wholly removed from the land.

Total Amounts of Salts Compatible with Ordinary Crops; Tolerance of Culture Plants.—Since the amount of alkali that reaches the surface layer is largely dependent upon the varying conditions of rainfall or irrigation, and surface evaporation, it is difficult to foresee to what extent that accumulation may go, unless we know the total amount of salts present that may be called into action. This, as already explained, can ordinarily be ascertained by the examination of one sample representing the average of a soil column of four feet. By calculating the figures so obtained to an acre of ground, we can at least approximate the limits within or beyond which crops will succeed or perish. Applying this procedure to the cases represented in the diagrams (pp. 434, 452, chapter 22) and estimating the weight of the soil per acre-foot at 4,000,000 pounds, we find in the land on which barley refused to grow the figures 32,470 and 43,660 pounds of total salts per acre, respectively corresponding to 0.203 per cent. for the first figure (the second, representing only the two surface feet, is not strictly comparable). For the land on which barley gave a full crop, we find for the May sample 25,550 pounds, equivalent to 0.159 per cent. for the whole soil column of four feet. It thus appears that for barley the limits of tolerance lie between the above two figures. It should be noted that in this case a full crop of barley was grown even when the alkali consisted of fully one-half of the noxious carbonate of soda; proving that it is not necessary in every case to neutralize the entire amount of that salt by means of gypsum, which in the present case would have required about 9½ tons of gypsum per acre—a prohibitory expenditure.

Relative Injuriousness of the Several Salts.—Of the three sodium salts that usually constitute the bulk of "alkali," only the carbonate of soda is susceptible of being materially changed by any agent that can practically be applied to land. So far as we know, the salt of sodium least injurious to ordinary vegetation is the sulfate, commonly called Glauber's salt, which ordinarily forms the chief ingredient of "white" alkali. Thus barley is capable of resisting about five times more of the sulfate than of the carbonate, and quite twice as much as of common salt. Since the maximum percentage that can be resisted by plants varies materially with the kind of soil, it is difficult to give exact figures save with respect to particular cases. For the sandy loam of the Tulare substation, California, for instance, the maximum for cereals may be approximately stated to be one-tenth of 1 per cent. for salsoda; a fourth of 1 per cent. for common salt; and from forty-five to fifty one-hundredths of one per cent of Glauber's salt. For clay soils the tolerance is in general markedly less, especially as regards the salsoda; since in their case the injurious effect on the tilling qualities of the soil, already referred to, is superadded to the corrosive action of that salt upon the plant.

Effect of Differences in Composition of Alkali Salts on Beets.—The marked differences which may occur as the result of even slight variations in the proportions of the several salts is well illustrated in the subjoined diagram of observations made by Dr. G. W. Shaw, of the Cal. Expt. station, upon beet fields in the neighborhood of Oxnard, Cal. The lands lie not far from the sea-shore, and saline water underruns them for considerable distance inland. The soil and subsoil are quite sandy, so that it takes irrigation water only about seven hours to penetrate

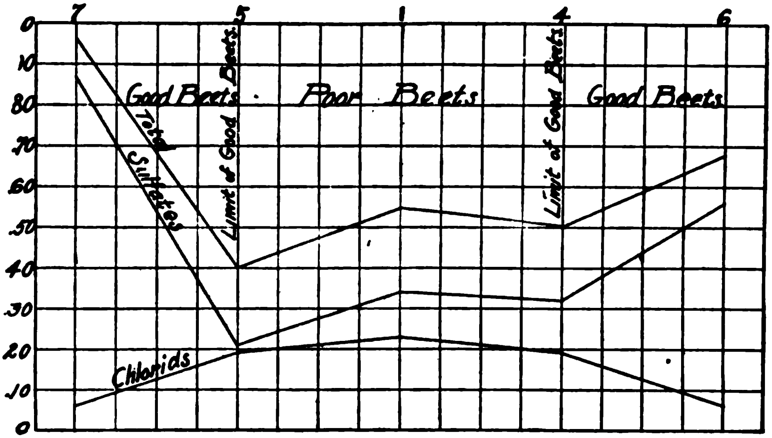

FIG. 73.—Alkali curve showing percentage of Alkali Salts in field of Sugar Beets, Oxnard, Calif.

FIG. 74.—Beets from corresponding positions in the above field.

from the surface to bottom water at seven feet depth. The land on which these observations were made are apparently level to the eye, though probably the alkali belts on which the sugar beets were "poor" are slightly depressed swales.

It will be noted that here the beets were "good" where the sulfate (Glauber's salt) ranged up to .8%, with .10 to .20 of common salt; but that so soon as the latter rose above .20, the beets were poor despite the low percentage of Glauber's salt; then became "good" again so soon as the common salt fell below .20%, although the Glauber's salt increased.

TOLERANCE OF VARIOUS CROP PLANTS.

The following table, compiled by Dr. R. H. Loughridge mainly from his own observations,[1] gives the details of the tolerance for various culture plants as ascertained at the several experiment substations in California, as well as at other points in that State and in Arizona where critical cases could be found. It is thought preferable to investigate analytically such cases in the field, rather than to attempt to obtain results from small-scale experiments artificially arranged, in which sources of error arising from evaporation and other causes are most difficult to avoid.

The table is so arranged as to show the maximum tolerance thus far observed for each of the three single ingredients, as well as the maximum of total salts found compatible with good growth. In view of the extremely variable proportions between the three chief ingredients found in nature, this seems to be the only manner in which the observations made can be intelligibly presented, until perhaps a great number of such data shall enable us to evolve mathematical formulæ expressing the tolerance for the possible mixtures for each plant. For it is certain that the tolerance-figures will be quite different in presence of other salts, from those that would be obtained for each salt separately; or for the calculated mean of such separate determinations, proportionally pro-rated. It must also be remembered that in all alkali soils, lime carbonate is abundantly present, as is, nearly always, a greater or less amount of the sulfate (gypsum). As already stated, according to the investigations of Cameron not only these compounds, but also calcium chlorid, exert a protective influence against the injury to plant growth from compounds of sodium and potassium. The figures here given can

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[1] Bulletins Nos. 128, 133 and 140, Calif. Expt. Station.

therefore be regarded only as approximations, subject to correction by farther observation. They are arranged from the highest tolerances downward, for each of the three ingredients, as well as for the totals. The latter are not, of course, the sums of the figures given in the preceding columns, but independent data.

HIGHEST AMOUNT OF ALKALI IN WHICH FRUIT TREES WERE FOUND UNAFFECTED.[1]

Arranged from highest to lowest. Pounds per acre in four feet depth.

Sulfates (Glauber's Salt).		Carbonate (Salsoda).		Chlorid (Common Salt).		Total Alkali.	
Grapes	40,800	Grapes	7,550	Grapes	9,640	Grapes	45,700
Olives	30,640	Oranges	3,840	Olives	6,640	Olives	40,160
Figs	24,480	Olives	2,880	Oranges	3,360	Almonds	25,560
Almonds	22,720	Pears	1,760	Almonds	2,400	Figs	26,400
Oranges	18,600	Almonds	1,440	Mulberry	2,240	Oranges	21,840
Pears	17,800	Prunes	1,360	Pears	1,360	Pears	20,920
Apples	14,240	Figs	1,120	Apples	1,240	Apples	16,120
Peaches	9,600	Peaches	680	Prunes	1,200	Prunes	11,800
Prunes	9,240	Apples	640	Peaches	1,000	Peaches	11,280
Apricots	8,640	Apricots	480	Apricots	960	Apricots	10,080
Lemons	4,480	Lemons	480	Lemons	800	Lemons	5,760
Mulberry	3,360	Mulberry	160	Figs	800	Mulberry	5,760
OTHER TREES.							
Kölreuteria	51,040	Kölreuteria	9,920	Or. Sycamore	20,320	Kölreuteria	73,600
Eucal. am	34,720	Or. Sycamore	3,200	Kölreuteria	12,640	Or. Sycamore	42,760
Or. Sycamore	19,240	Date Palm	2,800	Eucal. am	2,960	Eucal. am	40,400
Wash. Palm	13,040	Encal. am	2,720	Camph. Tree	1,420	Wash. Palm	15,200
Date Palm	5,500	Wash. Palm	1,200	Wash. Palm	1,040	Date Palm	8,328
Camph. Tree	5,280	Camph. Tree	320			Camph. Tree	7,020
SMALL CULTURES.							
Saltbush	125,640	Saltbush	18,560	Modiola	40,860	Saltbush	156,720
Alfalfa, old	102,480	Barley	12,170	Saltbush	12,520	Alfalfa, old	110,320
Alfalfa, young	11,120	Bur Clover	11,300	Sorghum	9,680	Alfalfa, young	13,120
Hairy Vetch	63.720	Sorghum	9,840	Celery	9,600	Sorghum	81,360
Sorghum	61,840	Radish	8,720	Onions	5,810	Hairy Vetch	69,360
Sugar Beet	52.640	Modiola	4,760	Potatoes	5,810	Radish	62,840
Sunflower	52,640	Sugar Beet	4,000	Sunflower	5,440	Suuflower	59,840
Radish	51,880	Gluten Wheat	3,000	Sugar Beet[2]	10,240	Sugar Beet	59,840
Artichoke	38,720	Artichoke	2,760	Barley	5,100	Modiola	52,420
Carrot	24,880	Lupin	2,720	Hairy Vetch	3,160	Artichoke	42,960
Gluten Wheat	20,960	Hairy Vetch	2,480	Lupin	3,040	Carrot	28.480
Wheat	15,120	Alfalfa	2,360	Carrot	2,360	Barley	25,520
Barley	12,020	Grasses	2,300	Radish	2,240	Gluten Wheat	24,320
Goat's Rue	10,880	Kaffir Corn	1,800	Rye	1,720	Wheat	17,280
Rye	9,800	Sweet Corn	1,800	Artichoke	1,480	Bur Clover	17,000
Cañaigre	9,160	Sunflower	1,760	Gluten Wheat	1,480	Celery	13,680
Ray Grass	6,920	Wheat	1,480	Wheat	1,160	Rye	12,480
Modiola	6,800	Carrot	1,240	Grasses	1,000	Goat's Rue	11,800
Bur Clover	5,700	Rye	960	White Melilot	440	Lupin	11,200
Lupin	5,440	Goat's Rue	760	Goat's Rue	160	Cañaigre	9,360
White Melilot	4,920	White Melilot	480	Cañaigre	80	Onions	38,480
Celery	4,080	Cañaigre	120			Potatoes	38,480
Saltgrass	44.000	Saltgrass	136,270	Saltgrass	70,360	Saltgrass	381,110

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[1] The several columns of figures are independent of each other; the "total" alkali is not the summation for the three salts in the same line.

[2] Figures taken from Bulletin 169, Calif. Expt. Station, June, 1905.

Comments on the Above Table.—Considering in this table, first, the plants suitable for the stronger class of alkali lands, it may be said generally that the search for widely acceptable kinds has not been very successful. It is true that cattle will nibble green salt grass (*Distichlis spicata*), but will soon leave it for any dry feed that may be within reach. The enormous amount of salts which it will tolerate in the soil on which it grows, and the doubtless correspondingly large amount of those salts which it will absorb, judging from its taste, sufficiently explain the reluctance of cattle to feed on it to any considerable extent.

The same is true of all the fleshy plants that grow on the stronger alkali lands, and are known under the general designation of "alkali weeds." When stock unaccustomed to it are forced by hunger to feed on such vegetation to any considerable extent, disordered digestion is apt to result; which in such ranges, however, is often counteracted by feeding on aromatic or astringent antidotes, such as the gray sagebrush and the more or less resinous herbage of plants of the sunflower family.

In the Great Basin region, lying between the Sierra Nevada and the front range of the Rocky Mountains, there are, aside from the grasses, numerous herbaceous and shrubby plants that afford valuable pasturage for stock,[1] and some of these grow on moderately strong alkali land; the same is true in California. It is quite possible that some of these will be found to lend themselves to ready propagation for culture purposes as well as they do for restocking the ranges. But thus far none have found wider acceptance, probably because their stiff branches and upright habit render them inconvenient to handle. It will require more extended experience and experiment before any of these will be definitely adopted for propagation by farmers and stockmen.

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[1] See Bulletin No. 16 of the Wyoming Experiment Station; also Bulletin Nos. 2 and 12 of the Division of Agrostology, and Farmers' Bulletin No. 108, U. S. Department of Agriculture.

Saltbushes, and Herbaceous Crops.

Australian Saltbushes.—Experience in California indicates that in the more southerly portion of the arid region, unpalatable native plants may be largely replaced, even on the ranges, by one or more species of the Australian saltbushes (*Atriplex spp.*), long ago recommended by Baron von Mueller of Melbourne; of which one (*A. semibaccata*) has proved eminently adapted to the climate and soil of California and is readily eaten by all kinds of stock. The facility with which it is propagated, its quick development, the large amount of feed yielded on a given area, even on the strongest alkali land ordinarily found, and its thin, flexible stems, permitting it to be handled very much like alfalfa, seem to commend it especially to the farmers' consideration wherever better forage plants cannot be grown and the climate will permit of its use. It does not, however, resist the severe cold of the interior plateau country, and is wholly out of place in the Pacific Coast region where summer fogs prevail. Most of the other Australian species have an upright, shrubby habit, which adapts them better to browsing than to pasture proper. The same is true of the Argentine species (*A. Cachiyuyum*), which in its native pampas is highly esteemed for that purpose, and succeeds well in California. Of other Australian saltbushes, *A. halimoides, vesicaria* and *leptocarpa* are the most promising; the latter is somewhat similar in habit to the semibaccata, but is not as vigorous a grower. Since some of the saltbushes take up nearly one fifth of their dry weight of ash ingredients,[1] largely common salt, the complete removal from the land of a five-ton crop of saltbush hay will take away nearly a ton of the alkali salts per acre. This will in the course of some years be quite sufficient to reduce materially the saline contents of the land, and will frequently render possible the culture of ordinary crops.

Modiola.—Alongside of the saltbushes, the Chilean plant

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[1] Analyses made at the California station show 19.37 percent of ash in the air-dry matter of Australian saltbush. (See California Station Bulletin No. 105; E. S. R., vol. 6, p. 718). Analyses of Russian thistle have been reported showing over 20 per cent of ash in dry matter. (See Minnesota Sta. Bulletin No. 34; Iowa Sta. Bull. No. 26; E. S. R., vol. 6, pp. 552–553).

Modiola procumbens, now generally known as modiola simply, deserves attention, as it makes acceptable pasture where alfalfa fails to make a stand on account of alkali. It is a trailing plant with medium-sized, roundish foliage, and roots freely at the joints where they touch the ground. Unlike the saltbushes it is therefore a formidable weed where it is not wanted; but as according to California experience it resists as much as 52,000 pounds of salts per acre, even when 41,000 of these is common salt, it is likely to be useful in many cases, particularly as an admixture to a saltbush diet for stock, as it does not absorb as much salt as the latter. It seems best adapted to pasturage.

As the table shows that, once grown to the age of a few years, alfalfa will resist a percentage of alkali next to the saltbush, it will generally be worth while, in lands otherwise adapted to alfalfa, to prepare the land by leaching-down (see above) so as to secure a stand of the more valuable crop.

Native Grasses.[1]—Of all known plants that stock will eat somewhat freely, the tussock grass (*Sporobolus airoides,* of which a figure is given farther on), a native of the southern arid region, endures the largest amounts of alkali; having been found growing well on land containing the enormous amount of nearly half a million pounds of salts per acre, although it will thrive with only 49,000 pounds in the soil. What it will do under cultivation has never been fairly tested; but its bare tussocks, killed by the excessive browsing of stock, testify to its acceptableness as forage. It does not seem to absorb excessive amounts of salts.

Aside from the alkali grass proper (*Distichlis*), mentioned above, the so-called rye grass of the Northwest (*Elymus condensatus*) is probably, next to the tussock grass, the most resistant species among the wild grasses. Its southern form, with several others not positively identified, occupies largely the milder alkali lands of southern California. This grass, though rather coarse, is regularly cut for hay in the low grounds of Oregon and Washington.

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[1] It should be understood that the plants so referred to are exclusively the *true* grasses, reeognized as such by every child, and not forage plants generally; which are sometimes so designated; not only by farmers, but by some authors who fail to appreciate the practical importance of the distinction, which makes it necessary that farmers should be taught to understand it.

Doubtless some of the indigenous grasses of the interior plateau region and of the great plains east of the Rocky Mountains, such as the buffalo and grama grasses, as well as several of the wheat grasses (*Agropyron*) and bunch grasses (*Festuca, Poa, Stipa,* etc.) will prove resistant to larger proportions of alkali than the meadow and pasture grasses of the regions of summer rains.

Cultivated Grasses.—The superficial rooting and fine fibrous roots of the true annual grasses render them, as a whole, rather sensitive to alkali; yet the cereals—barley, wheat, rye and oats—resist, as the table shows, the average alkali salts to the extent of from 17,000 total salts, with not exceeding 1500 pounds of carbonate, in the case of the more delicate varieties of wheat, to over 25,000 pounds per acre in the case of barley, which with the gluten wheats and rye seems to have the highest tolerance-figure. The special adaptation of gluten wheats to arid conditions is thus emphasized. The roots of these cereals are comparatively stout, with thick epidermis.

Among the cultivated forage grasses proper, the Australian variety of the English ray (generally miscalled rye) grass seems most resistant. The eastern fescues, Kentucky blue grass, and others at home in the humid region are easily injured, as those who try to maintain lawns on alkali-tainted lands, or by irrigation with alkali waters, know to their sorrow. To these grasses common salt and bittern (magnesium chlorid) seem to be particularly injurious, and they tolerate but little "black alkali."

On the rather close-textured soil at Chino, California, the loliums, including the darnel ("California cheat"), and the Australian and Italian ray ("rye") grasses, succeed fairly on land containing as much as 6,000 pounds of (white) salts. Most other cultivated grasses failed conspicuously alongside of these. It must be remembered that in more loose-textured, sandy lands than those in which these tests were made, the above figures for tolerance would probably be increased by 30 percent or more.

Maize is rather sensitive to alkali, and suffers even on slightly alkaline land, owing doubtless to the large development of fine white rootlets near the surface, so familiar to corn-growers. The *Sorghums,* and especially Egyptian corn (durra) are much less sensitive, as the table shows, and are among the first crops to be tried on alkali lands. The related millets share this resistance more or less, and we often see on cultivated lands in the alkali region fine stands of barnyard grass (*Panicum crusgalli*) of which the variety (?) *P. muticum* is said by observers of the U. S. Dept. of Agriculture to be specially resistant, and acceptable to stock. One of the most successful grasses on the light alkali lands near Chino, where most of the commonly cultivated grasses fail, was a near relative of the barnyard grass, the *Eleusine coracana,* which produces heavy crops of a millet-like grain much relished by poultry, and also by stock. This grass, largely grown in Egypt, has succeeded well all over the ground whose alkali content ranges up to 12,000 pounds per acre, but failed where the salts reached 38,840 pounds in the surface foot. Next to this, in point of success, were the pearl millet (*Pennisetum typhoideum*) and teosinte, Hungarian brome grass, and Japanese millet, on land containing about 9,000 pounds of (chiefly "white") salts per acre.

Other Herbaceous Crops. Legumes.—Both the natural growth of alkali lands and experimental tests seem to show that this entire family (peas, beans, clovers, etc.) are among the more sensitive and least available wherever black alkali exists; while fairly tolerant of the white (neutral) salts. Apparently a very little salsoda suffices to destroy the tubercle-forming organisms that are so important a medium of nitrogen-nutrition in these plants. Excepting the melilots, alfalfa with its hard, stout and long taproot, seems to resist best of all these plants.

As a general thing, taprooted plants, when once established, resist best, for the obvious reason that the main mass of their feeding roots reaches below the danger level. Another favoring condition, already alluded to, is heavy foliage and consequent shading of the ground; alfalfa happens to combine both of these advantages. There has been some difficulty in obtaining a full stand of alfalfa in the portion of the Chino substation tract containing from 4000 to 6000 pounds of (largely black) alkali salts per acre; but once obtained, it has done very well.

The only other plant of this family that succeeds well on this land, and even (at Tulare) on soil considerably stronger (probably between 20,000 and 30,000 pounds) are the two melilots, *M. indica*, and *alba;* the latter (the Bokhara clover) is a forage plant of no mean value in moist climates, but somewhat restricted in its use in the arid region because of the very high aroma it develops, especially in alkali lands; so that stock will eat only limited amounts, best when intermixed with other forage, such as the saltbushes. The yellow melilot is highly recommended by the Arizona Experiment Station as a green-manure plant for winter growth; but farther north it is a summer-growing plant only, and is refused by stock. As already stated, very few plants belonging to this family are naturally found on alkali lands, and attempts to grow them, even where only Glauber's salt is present, have been but very moderately successful.

For most of the legumes the limit of full success seems to lie between 3000 and 4000 pounds to the acre. A marked exception, however, occurs in the case of the hairy vetch, as shown in the table, where it is credited, on the basis of repeated experiments, with a tolerance of nearly 70,000 pounds. This amount was attained, however, in rather sandy soils. Probably some of the Algerian vetches will likewise prove more resistant than those which are natives of humid climates.

Mustard Family.—As in the case of the legumes, wild plants of the *mustard* family are rare on alkali lands; and correspondingly, the cultivated mustard, kale, rape, etc., fail even on land quite weak in alkali. Their limit of tolerance seems to lie near 4,000 to 5,000 pounds per acre even of white salts. Hence turnips and radishes do not flourish on alkali lands.

Sunflower Family.—Several of the hardiest of the native "alkali weeds" belong to the *sunflower* family, and the common wild sunflowers (*Helianthus californicus* and *H. annuus*) are common on lands pretty strongly alkaline. The cultivated Russian sunflower, as the table shows, resists the effects of nearly 60,000 pounds of total alkali, of which 52,640 pounds was sulfate (Glauber's salt), and 5440 common salt. This, it will be seen, is a very high tolerance, so that this sunflower, yielding such excellent poultry feed, is very widely available Correspondingly, the "Jerusalem artichoke," itself a sunflower, is among the available crops on moderately strong alkali soils; and so, doubtless, are other members of the same relationship not yet tested, such as the true artichoke, salsify, etc. Chicory, belonging to the same family, yielded roots at the rate of twelve tons per acre, on land of the Chino tract containing about 8,000 pounds of salts per acre.

Root Crops.—It seems to be generally true that root crops suffer in quality, however satisfactory may be the quantity, harvested on lands rich in salts, and especially in chlorids (common salt). It was noted at the Tulare substation (California) that the tubers of the artichoke were inclined to be " squashy " in the stronger alkali land, and failed to keep well; the same was true of potatoes, which were very watery; and also of turnips and carrots. It is a fact well known in Europe, that potatoes manured with kainit (chlorids of potassium and sodium) are unfit for the manufacture of starch, and are generally of inferior quality. But this is found not to be the case when, instead of the chlorids, the sulfate is used; hence the advice, often repeated by the California station, that farmers desiring to use potash fertilizers should call for the " high-grade sulfate " instead of the cheaper kainit, which adds to the injurious salts already so commonly present in lowland soils of the arid region. Such root crops are, however, available for stock feed.

The common *beet* (including the mangel-wurzel) is known to succeed well on saline seashore lands, and it maintains its reputation on alkali lands also. Being especially tolerant of common salt, it may be grown where other crops fail on this account; but the roots so grown are strongly charged with common salt, and have, as is well known, been used for the purpose of removing excess of the same from seacoast-marsh lands. Such roots are wholly unfit for sugar-making.

It is quite otherwise with Glauber's salt (sodium sulfate); and as this is very commonly predominant in alkali lands, either before or after the gypsum treatment, this fact is of great importance, for it frequently permits of the successful growing of the sugar beet; as has been abundantly proved at the Chino ranch, where land containing as much as 60.000 pounds of salts, mostly this compound, has yielded roots of very high grade, both as to sugar percentage and purity. But the analyses of the Oxnard soil show that more than 10,000 pounds of common salt will be required to render sugar beets unsatisfactory for sugar-making.

Passing to *stem crops,* we find that *asparagus,* originally itself a denizen of the sea-board, resists considerable amounts (not yet exactly determined) of common salt as well as of Glauber's salt. It is even claimed that when grown with a dressing of common salt the asparagus is more tender and savory. But it is quite sensitive to "black alkali," which must be neutralized with gypsum to render it harmless.

Celery did well with 13,640 pounds, of which nearly 10,000 was common salt. But with 30,000 pounds the plants were killed.

Rhubarb was a conspicuous failure, even in the weak and mostly "white" alkali lands of the Chino station tract.

Textile Plants.—Japanese hemp, while young, seemed to have a hard struggle with the alkali, but at the end of the season stood eight feet high. The *ramie* plant, also, will bear moderately strong alkali, apparently somewhat over 12,000 pounds per acre. *Flax* has not been tested in cultivation; but the wide distribution of wild flax all over the arid portions of the States of Oregon and Washington, would seem to indicate that it is not very sensitive. Another textile plant, the Indian mallow (*Abutilon avicennae*), was found to fail on the Chino alkali soil. But its close relative, cotton, does not seem to be specially sensitive, according to the experience had with it in the Merced river bottom in California; and its culture is extensive in Egypt, where no particular care seems to be exercised in selecting the land for the crop. It is just possible that the saline content of the soil has in California, as well as in the Atlantic sea-islands, contributed to the superior length of the fiber shown in the measurements made during the Census work of 1880.[1]

Tolerance of Shrubs and Trees.

Grapevines.—The European grape, *Vitis vinifera,* is quite tolerant of white or neutral alkali salts, and will resist even a moderate amount of the black so long as no hardpan is allowed to form. At the Tulare substation it was found that grape-

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[1] Report on Cotton Culture; 10th Census of the United States, vol. 5, pp. 23 to 34.

vines did well in sandy land containing 35,230 pounds of alkali salts, of which one half was Glauber's salt, 9,640 pounds carbonate of soda, 7,550 pounds of common salt, and 750 pounds nitrate of soda. They were badly distressed where, of a total of 37,020 pounds of alkali salts, 25,620 pounds was carbonate of soda; while where the vines had died out, there was found a total of 73,930 pounds, with 37,280 pounds of carbonate. The European vine, then, is considerably more resistant of alkali even in its worst (black) form, than barley and rye, at least on sandy land; and it seems likely that the native grapevines of the Pacific coast, *californica,* and *arizonica,* would resist even better; a point still under experiment.

Experience, however, has shown that vines rapidly succumb when by excessive irrigation the bottom water is allowed to rise, increasing the amount of alkali salts near the surface, and shallowing the soil at their disposal. Such over-irrigation has been a fruitful cause of injury to vineyards in the Fresno region, and would doubtless if practiced kill most of the vines at the Tulare substation, which are now flourishing. In such cases, sometimes the formation of hardpan is followed by that of a concentrated alkaline solution above it, strong enough to corrode the roots themselves, and not only killing the vines, but rendering the land unfit for any agricultural use whatsoever. The swamping of alkali lands, whether of the white or black kind, is not only fatal to their present productiveness, but, on account of the strong chemical action thus induced, greatly jeopardizes their future usefulness. Many costly investments in orchards and vineyards have thus been rendered unproductive, or have even become a total loss.

It should be remembered in this connection that as the roots of vines will, when unobstructed, go to depths of fifteen and even twenty feet, a subsequent rise of the bottom water from leaky irrigation ditches will drown out the ends of the deep roots and thus cause the whole root system to become diseased, inevitably resulting in unproductiveness, if not death, of the vine.

Citrus Trees.—Although the high figure of nearly 27,000 pounds for the tolerance of citrus trees, as given in the table, seems to place them rather high on the list, such high tolerance actually occurs only in very sandy soils, and when common salt is in small proportion. Generally speaking, the citrus tribe are rather sensitive to alkali salts, and more especially to common salt. In fact, as to the high tolerance-figure given in the table, observed in sandy land, the alkali there contained only a trace of common salt. Young seedling trees are particularly sensitive; so that it is often difficult to obtain a stand even when, later on, the feeding roots descend beyond the reach of injury. In the close-textured lands of Chino, young trees hardly maintained life with more than 5,000 pounds of total salts. Near Riverside, full-grown trees perished under the influence of bottom water containing 0.25%, or 146 grains of salt per gallon, which impregnated the ground; corresponding to about 9,000 pounds per acre in four feet.

In the sandy loam lands near Corona, trees eight years old suffered severely when by irrigation with alkali-water the alkali-content of the land reached 11,000 pounds per acre; as illustrated in Figs. Nos. 44, and 45. At another point in the same region, two representative trees were selected for comparison, five rows apart on land absolutely identical; one of these retained its leaves, though suffering, the other was completely leafless. The leaching of the alkali to the depth of four feet gave the following results, calculated to pounds per acre:

	Sulfates.	Carbonates.	Chlorids.	Total.
Poor tree.....	4,720	1680	2,520	8,920
Better tree...	4,120	2,360	720	7,200

Here it is apparently the excess of common salt to which the difference is due, and this despite the higher content of carbonate of soda in the soil bearing the better tree.

On the other hand, at the Tulare substation orange trees (sour stock) maintain vigorous growth and good bearing in a very sandy tract which to the depth of seven feet showed an aggregate content of 26,840 pounds of salts (or 22,780 to four feet depth); but which is never irrigated. (See diagram No. 66). The salts in this case consists wholly of sulfate and carbonate of soda in the ratio of fifty-four to forty-two, implying the presence of nearly 12,000 pounds of salsoda within reach of the tree roots; yet in the absence of common salt, no perceptible injury or even stress upon the trees has been noted.

According to observations made in San Diego county, Calif., lemon trees are even more sensitive to common salt than oranges, since a total content of 8,000 pounds per acre, about one-third of which was common salt, seemed to render the trees wholly unprofitable.

In view of these facts, showing that common salt is the portion of alkali by far most injurious to citrus trees, great care should be taken in the use of irrigation waters to exclude those charged with that compound; and also to avoid locating citrus orchards on land already impregnated with common salt.

The *olive* tree, as the table shows, is among the most resistant to alkali salts, approaching the grape in this respect. This might have been anticipated from its extended culture in the arid regions of the old world, including Palestine and northern Africa, where alkali lands abound. It is probable that the figure given in the table does not yet show the extreme limit of its endurance.

California experience with the *date palm,* as the table shows, credits it with an endurance not exceeding 8320 pounds of total salts. This is doubtless an underestimate, for in the Sahara desert and Egypt it is credited with being the culture which will succeed in stronger alkali than any other cultural plant; and, according to Mr. Means of the United States Department of Agriculture, it is sometimes irrigated with water containing as much as 200 grains of salts per gallon. It should be remembered, however, that these trees always grow in very sandy lands; and in the desert regions it is often grown below the surface of the ground, so as to render it wholly independent of the alkali accumulations on the surface. The extreme limit of its endurance must therefore remain in doubt until more extended experiments have made more definite data available.

Deciduous Orchard Trees.

Among deciduous orchard trees, strangely enough, the *almond* stands alongside of the fig in alkali-resistance, as indicated in the table. The *peach* seems to be much more sensitive, ranking near the *apricot* and *prune,* whose tolerance is less than half as high. That the *pear* and *apple,* generally counted among the more northern fruits in the humid region, should excel these stone fruits in endurance of alkali, is rather unexpected; and the figures concerning the whole group of these rosaceous fruits admonish us that it is unsafe to predict, without trial, what may be the outcome of culture tests. Thus plum trees, apparently in good condition, sometimes suddenly begin to fail when starting to bear; the fruit appears normal on the outside for a time, but the pit fails to form, being at times flattened out like a piece of pasteboard; and the fruit does not mature. Yet there is no observable injury to the base of the trunk, or to the roots. On the other hand, pears do well even when the outside bark around the root-crown is blackened by the action of the alkali salts. But 38,000 pounds, even of sulfate, proves too much for the pear.

The *quince* appears to be materially more resistant than the apple or pear. It probably ranges alongside of the fig, the soil-adaptations of which it shares in other respects also.

The *English walnut* resents even a slight taint of *black* alkali; but is fairly tolerant of " white " salts, as is shown in the peculiarly suitable light loam soils on the lower Santa Clara river, in Ventura county, as well as in Orange county, California.

Close figures for the limits of alkali tolerance in the case of deciduous orchard trees cannot easily be given or determined, owing to the difficulties inherent in the differences of root penetration in the several soils and localities; as well as the fact already alluded to, that in close-textured soils the tolerance is in general decidedly less than in sandy lands. Hence the figures in the table must be taken as more nearly representing *relative* tolerances, rather than absolute data to be applied in every case. As regards the stone fruits, it should be remembered that the Myrobalan root, being at home in Asia Minor, where alkali abounds, should when practicable be used wherever alkali conditions exist, in preference to all but the almond, which seems to resist well, even on its own root, but has not as wide a range of adaptations as a grafting stock as the myrobalan. While most of the other stone fruits at the Tulare substation were on myrabalan roots, the stock of those in outside orchards was mostly in doubt. It is also to be kept in mind that different varieties of the same fruit—*e. g.*, pears and apples—show a not inconsiderable variation in their resistance.

Timber and Shade Trees.

Of trees, forest and shade, suitable for alkali lands, some native ones call for mention. One is the California white or valley oak (*Quercus lobata*), which forms a dense forest of large trees on the (almost throughout somewhat alkaline) delta lands of the Kaweah River in California, and is found scatteringly all over the San Joaquin Valley. Unfortunately this tree does not supply timber valuable for aught but firewood or fence posts, being quite brittle.

The native *cottonwoods,* while somewhat retarded and dwarfed in their growth in strong alkali, are quite tolerant of the white salts, especially of Glauber's salt. As they usually grow near to the water, their tolerance for alkali salts is difficult to ascertain.

Of other trees, the *oriental plane,* or sycamore, and the *black locust* have proved the most resistant in the alkali lands of the San Joaquin Valley; and the former being a very desirable shade tree, it should be widely used throughout the regions where alkali prevails more or less. The *ailantus* is about equally resistant, and but for the evil odor of its flowers, deserves strong commendation.

Of the *eucalypts,* the narrow-leaved *Eucalyptus amygdalina* (one of the "red gums") and the closely related *viminalis,* seem to be least sensitive, and in some cases have grown in alkali lands as rapidly as anywhere. The *rostrata,* as well as the pink flowered variety of *sideroxylon,* are now doing about as well as the *amygdalina* at Tulare, where at first they seemed to suffer. The common blue gum, *globulus,* is much more sensitive.

Of the *Acacias,* the tall-growing *A. melanoxylon* ("black acacia") resists pretty strong alkali, even on stiff soil; as can be seen at Tulare and Bakersfield, California, where there are trees nearly two feet in diameter. The beautiful *A. lophantha* (*Albizzia*) has in plantings made along the San Joaquin Valley railroad shown considerable resistance, likewise; but it is quite sensitive to frost.

Of other Australian trees, one of the Australian "pines," (*Casuarina equisetifolia*), is doing well on fairly strong alkali land in the San Joaquin Valley.

A remarkably alkali-resistant shrub or small tree is the pretty *Kœlreuteria paniculata* from China, which at Tulare is growing in some of the strongest alkali soil of the tract. Unfortunately it is available mainly for ornamental purposes; its wood, while small, is very hard and makes excellent fuel.

Of trees indigenous to the Atlantic and East Central United States, the Tulip tree, the Linden, and most other trees of the humid region, including the English oak (*Quercus pedunculata*) become stunted in alkali soils. The *honey locust,* being particularly adapted to calcareous lands, does moderately well on alkali lands, but its thorns and imperfect shade render it not very desirable. The *black locust* and the *elms* have on the whole done best. The eastern maples are not successful; but the California maple (*Acer macrophyllum*) and the box elder (*Negundo californica*) have done fairly well in the lighter alkali lands of the San Joaquin Valley.

The *Conifers*—Pines, firs, cedars, cypress, etc., are very sensitive to black alkali and will not endure much even of the "white" salts. Even the native juniper of the mesas carefully adheres to the portions—breaks and upper slopes, hilltops, etc. —which are more or less leached by the scanty rains of these regions.

INDUCEMENTS TOWARD THE RECLAMATION OF ALKALI LANDS.

The expense involved in the reclamation of strong alkali lands naturally gives rise to the question whether adequate advantages are likely to be derived from such expenditure; specially when the last resort—underdraining and leaching—has to be adopted.

Those familiar with the alkali regions are aware how often the occurrence of alkali spots interrupts the continuity of fields and orchards, of which they form only a small part, but enough to mar their aspect and cultivation. Their increase and expansion under irrigation frequently renders their reclamation the only alternative of absolute abandonment of the investments and improvements made, and from that point of view alone it is of no slight practical importance. Moreover, the occurrence of vast continuous stretches of alkali lands within the otherwise most eligibly situated valley lands of the irrigation region forms a strong incentive towards their utilization.

There is, however, a strong intrinsic reason pointing in the same direction, namely, the almost invariably high and lasting productiveness of these lands when once rendered available to agriculture. This is foreshadowed by the usually heavy and luxuriant growth of native plants around the margins and between alkali spots (see fig. 60); *i. e.*, wherever the amount of injurious salts present is so small as not to interfere with the utilization of the abundant store of plant-food which, under the peculiar conditions of soil-formation in arid climates, remains in the land instead of being washed into the ocean. Extended comparative investigations of soil composition, as well as the experience of thousands of years in the oldest settled countries of the world, demonstrate this fact and show

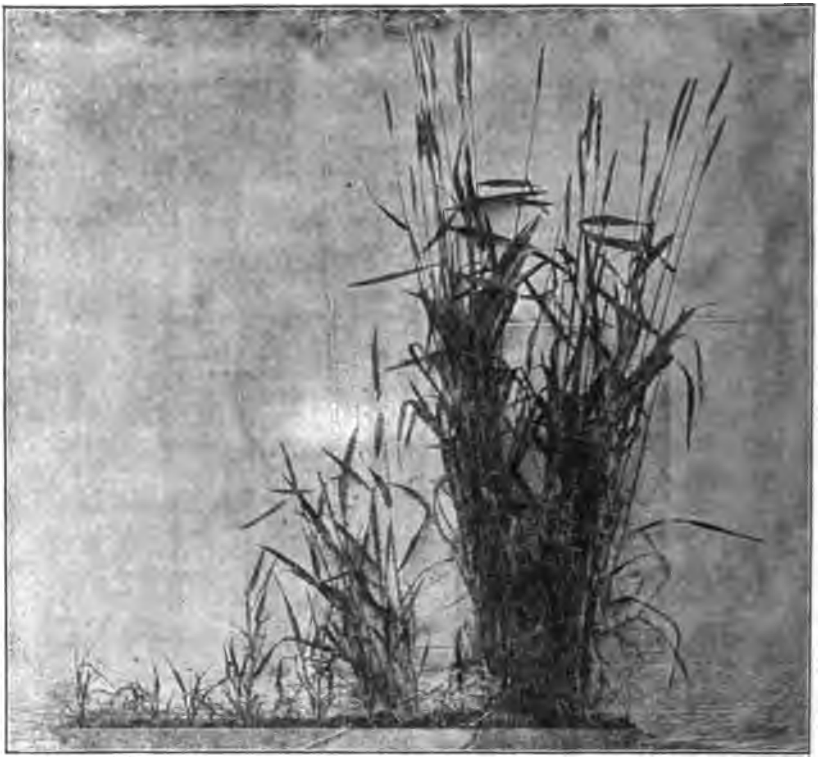

Fig. 75.—Wheat grown on black alkali land at Tulare Substation, California, showing improvement in successive years of reclamation treatment.

that so far from being in need of fertilization, alkali lands usually possess extraordinary productive capacity whenever freed from the injurious influence of the excess of useless salts left in the soil in consequence of deficient rainfall. (See analyses, chapter 22, pp. 436, 437).

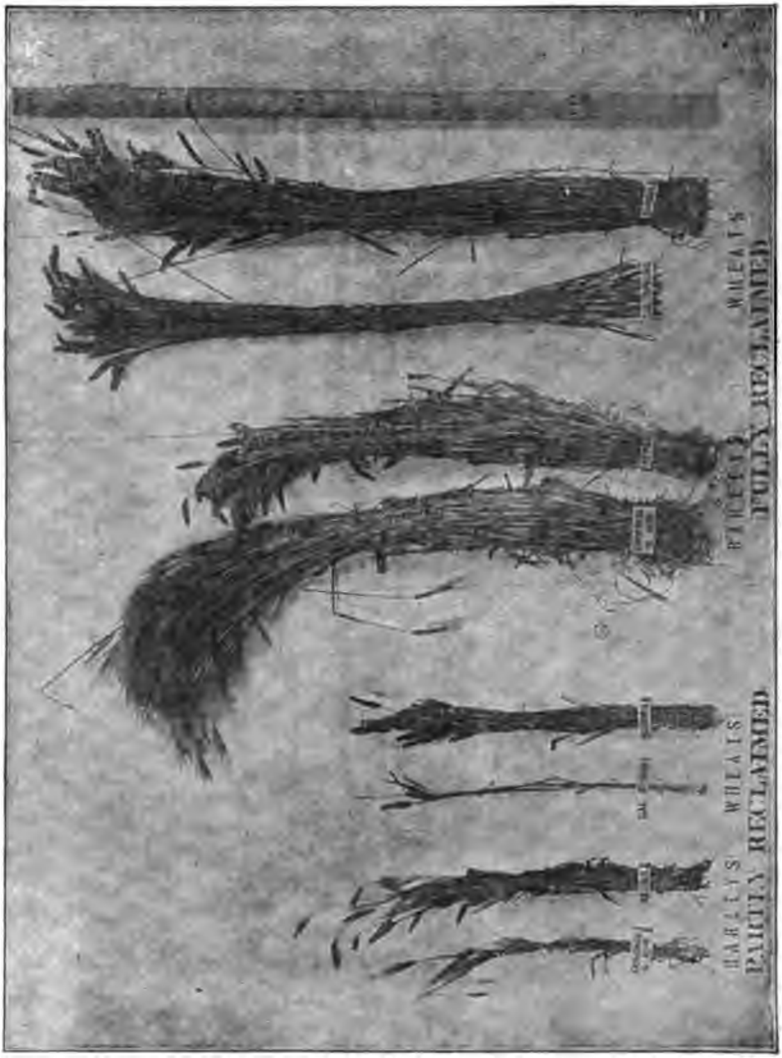

FIG. 76.—Grains grown on alkali land at Tulare Station, California.

Among many striking examples of the results of such reclamation, is that represented in the annexed figure (75), of grain grown on strong alkali land, before and after reclamation treatment. On the original land even "alkali weeds" would hardly grow; while afterward a wheat crop representing forty-two bushels per acre was grown. Additional illustrations are shown in the second figure (76), showing crops of wheat and barley as grown on partly reclaimed land at the Tulare substation.

While it is certainly true that when rightly treated, alkali lands can be rendered profusely and lastingly productive, yet close attention and constant vigilance are needed so long as the salts remain in the soil; and no one not determined to give such land such full attention, should undertake to cultivate it.

PART FOURTH.

SOILS AND NATIVE VEGETATION.

CHAPTER XXIV.[1]

THE RECOGNITION OF CHARACTER OF SOILS FROM THEIR NATIVE VEGETATION; MISSISSIPPI.

Climatic and Soil-Conditions.—Next to climatic conditions, chief among which are temperature and moisture, the physical and chemical nature of the soil and subsoil is the most potent factor in determining the natural vegetation of any region. The limitations we observe in the adaptation of cultivated lands to certain crops, even with artificial help, must be much more strongly pronounced when no such aid is given, and the struggle for the survival of the fittest is continued, subject only to seasonal variations, for thousands of years. It is obvious that within the limits of the regional flora, *the natural vegetation of any tract represents the best adaptation of plants to soils, in the results of long periods of the struggle for existence between competing species;* the survivors being those best adapted to the entire environment.

In countries uninhabited by man the chief conditions outside of the direct influence of climate and soil that may materially affect the results of the competition are connected with the animal creation; and within the latter, insects are probably the most influential, beneficially in the part they play in the fertilization of flowers, injuriously in their role as parasites. Since in the absence of man, the effects of fire would ordinarily be conditioned upon the occurrence of thunderstorms, its effects would then properly come under the head of climatic influences. But while these and some other disturbing factors must not be forgotten in considering the relations of soils to the natural vegetation borne by them, the common consensus of mankind has long recognized the intimate connection existing between the two, and has everywhere made it the basis of at least a general estimate of the agricultural value of the land concerned.

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[1] The special object of this chapter as a whole has seemed to the writer to require a repetition of much that is already said in the preceding chapters.

NATURAL VEGETATION THE BASIS OF AGRICULTURAL LAND VALUES IN THE UNITED STATES.[1]

In countries long settled, as in Europe, where the nature of the original forest is unknown or a matter of tradition only, the adaptations of the several kinds of land to culture plants and forest trees has been gradually ascertained by cultural experience, and their designations, values and uses determined accordingly. In the United States, the character of the original forest growth is mostly in evidence, or is definitely known by tradition, even in the older states. West of the Alleghenies, there is as yet little difficulty in this regard, partly because even where the original forest growth has disappeared its character remains on record, the assessed land values being very commonly based upon the tree growth of the wild land. In the Southern States especially, the classification of uplands into "pine lands" and "oak lands" is universal, and is associated with certain limits of valuation, both by assessors and purchasers. Within each of these two classes, however, there are well-defined gradations of cultural value according to the kind (species) *e. g.*, of pine or oak that occupies the ground, either alone, or in intermixture with other trees whose presence or absence is considered significant. In the case of "bottoms" or alluvial lands, corresponding distinctions and classifications obtain; we hear of hickory, beech, gum, and cherry bottoms, hackberry hammocks, etc. each name being associated with certain cultural values or peculiarities of soil, well understood by the farming population.

INVESTIGATION OF CAUSES GOVERNING THE DISTRIBUTION OF NATIVE VEGETATION.

It seems singular that such well and widely understood designations and important distinctions should not long ago have been made the subject of careful investigation and precise definition by agricultural investigators. For apart from their practical importance as guides to the purchaser of land, or settler, this correlation of land-values and natural vegetation is of the utmost interest in offering an opportunity for researches on the factors which determine the choice of these several trees and the corresponding shrubby and herbaceous

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[1] See above, pp. 313 to 315, chapter 18.

growths. Moreover, the cultural results and adaptations corresponding to certain natural growths being known from experience, a thorough knowledge of the soils so characterized should enable us to project into new lands, where experience is lacking, the benefits of experience already had; even in cases where, from some cause, the natural vegetation is different, or absent. Only very fragmentary and casual observations in this line are on record thus far, almost the only generally recognized chemical characterization of plant habit being that of calciphile (lime-loving), and calcifuge (lime-repelled) ones, but with few attempts at more than local application. Yet, to ascertain by the physical and chemical examination of soils what are determining factors of certain natural vegetative preferences, which are invariably followed by certain agricultural results, should not be an unsolvable problem, and its practical importance should justify its most active investigation.

Investigations in Mississippi.—In his explorations connected with the Geological and Agricultural Survey of the State of Mississippi, as well as, later on, in similar researches carried on in other states, the writer was forcibly struck with the close correspondence of the limits of geological formations with those of vegetative zones; so much so that he was led to rely very largely on the latter as indicative of the probable occurrence of outcrops that otherwise, in a level country, would have passed unperceived.

These observations upon the correlations between virgin soils and their native vegetation having originally been made by the writer, in great detail, in the state of Mississippi, from 1855 to 1872, and that state being from natural causes a peculiarly cogent illustration of such correlation: it seems advisable to describe first, somewhat in detail, the facts observed there, and subsequently to compare them with what has been observed elsewhere by him or others.

No claim is made to an even approximately exhaustive presentation of the whole subject, even within the United States; nor is it intended to give complete lists of vegetation.[1] The

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[1] Such lists, so far as the State of Mississippi is concerned, may be found in the writer's Report on the Agriculture and Geology of Mississippi, 1860. See also Plant Life of Alabama, by Charles Mohr.

object is to give such facts as have been fairly well established by observation, hoping that more thorough investigations in the same line will thereby be stimulated.

VEGETATIVE BELTS IN NORTHERN MISSISSIPPI.

The diagram below is a sketch-map of the most northern part of Mississippi, showing the narrow parallel belts of successive geological formations or terranes running north and south, which bear the varying zones of vegetation characteristic of each one, as indicated in the legend beneath.

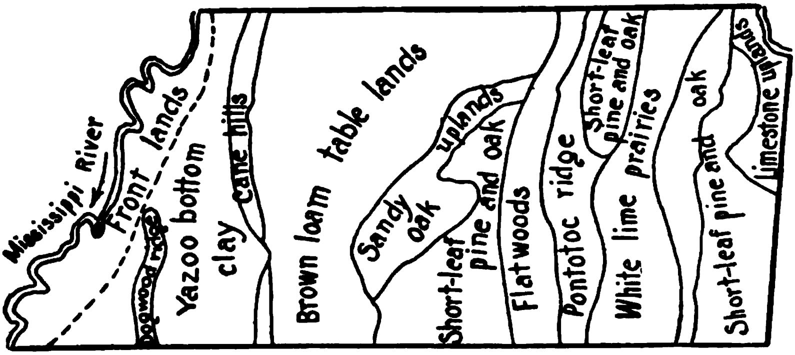

FIG. 77.—Sketch map of Soil Belts in Northern Mississippi, east and west.

SOIL REGIONS OF NORTHERN MISSISSIPPI, SHOWING CHANGES FROM EAST TO WEST, AND LIME PERCENTAGES IN SOILS.

	Lime, p.c.	Soil Character.	Vegetation.
1.	.40— .60	Clay loams, clay.	Oaks, sweet gum, tulip tree, walnut, red cedar, ash, hickories.
2.	.05— .14	Sandy loams, sands.	Short-leaf pine, post, scarlet and black-jack oaks, black gum, chestnut.
3.	1.00— 1.40	"White lime" prairie; clays and clay loams.	Red cedar, crab apple, Chickasaw plum, sturdy post and black-jack oaks, honey locust.
4.	.30— .50	Mellow red loams of "Pontotoc ridge."	Oaks, hickories, walnut, tulip tree, ash, cherry, umbrella tree.
5.	.08— .18	Heavy gray clay soils, some gray sands. "Flatwoods."	Scrubby post and black-jack oak, short-leaf pine.
6.	.15— .25	Sandy ridges and uplands, broken.	Post, black-jack, scarlet and upland willow oaks, small; some chestnut.
7.	.25— .35	Mellow clay loams of "Table lands."	Fine black, red, post, Spanish and black-jack oaks, hickories, sweet gum.
8.	2.00— 5.00	Calcareous sandy silt, "Bluff loess" "Cane Hills."	Oaks as above, tulip tree, ash, honey locust, linden, sassafras, umbrella tree, cane.
9.	.40— 1.10	*Mississippi Bottom*.	Basket, white and black oaks, ash, tulip tree, honey locust, pecan, shellbark hickory, walnut, hackberry, cane.
9a	1.12—	Yazoo backland buckshot clay.	
9b.	.40	Sandy alluvium, "Frontland.	Sweet gum, maple, willow oak, elm, hackberry.
10.	.26— .40	Light sandy loam of "Dogwood ridge."	Dogwood, sweet gum, holly, ash, sassafras, prickly pear.

Limestone Belt.—Beginning on the east we have, first, a narrow belt of limestones of the carboniferous formation, on which there is a fine growth of various oaks, with walnut, hickory, sweet gum, tulip tree and red cedar, and a very productive soil.

"*Pine Hills.*"—Next adjoining on the west comes a belt of sandy, non-calcareous beds of the lower Cretaceous formation, about 18 miles wide. It has a hilly surface, and outside of the narrow valleys, the prevalent timber is short-leaved pine and scrubby black-jack oak, with some post oak and small black gum, and a few large chestnut trees.

"*Prairie*" *Belt.*—Westward of this belt we descend into a level "prairie" region, six to twelve miles wide; the "white lime country," having heavy black clay soils, underlaid by the cretaceous "rotten limestones;" which are profusely productive. The sparse tree growth consists of stout, vigorous and dense-topped post and black-jack oaks, with clumps of crab apple, Chickasaw plum thickets, and an occasional red cedar.

Pontotoc Ridge.—West of the prairie belt we ascend into a ridgy hill country, twelve to fourteen miles wide; the "Pontotoc ridge," formed of the soft limestones and marls of the upper cretaceous formation, and covered with a deep red soil, which bears a rich growth of oaks, with hickory interspersed, and black walnut, umbrella and tulip tree even on the ridges. This is one of the finest agricultural regions of the State.

Flatwoods.—From the Pontotoc ridge and its fine lands and timber we descend to westward into the "Flatwoods" belt, three to eight miles wide; a level country underlaid by heavy gray non-calcareous clays of the tertiary formation, from which most of its soil is directly formed. It bears a pretty dense growth of the same species of oaks that characterize the prairies farther east, but the form, habit and size of the trees is so different that many of the inhabitants believe them to be different species. The black-jack oak looks like small, dense-topped apple trees; the post oak, on the contrary, has an open top of the form of a short-handled, spreading broom. The soil is poor and unthrifty, as are the few disappointed settlers, who bought the land on the strength of its oak-tree growth. (See page 500).

Brown Loam Region. Table Lands.—Adjoining the Flatwoods on the west is a broad upland region, with a brownish-yellow soil and subsoil, extending nearly to the edge of the Mississippi bottom. In its eastern portion it is rather broken and hilly, with sandy ridge soils, a mixed growth of oaks and short-leaved pine, and occasional chestnuts; a fair farming country only. To westward the ridges become lower and broader, assuming a plateau character. The pine disappears, and black, Spanish, red and white oak, with much hickory, largely replaces the black jack and post oak; thus characterizing the fertile brown-loam "table-lands" that extend through western Tennessee and Mississippi into Louisiana, and have long been noted for their high production of fine upland cotton.

Cane Hills.—On the western border of the table-land region, and here forming a strip only a few miles wide along the edge of the Mississippi bottom, but from 70 to 450 feet above it, lies the remnant of what farther south constitutes a wide and important agricultural belt; the Bluff or Loess formation, locally known as "the Cane Hills." The soil is largely composed of grains of sand and silt cemented by lime carbonate; it is therefore calcareous, and as on the Pontotoc ridge, described above, we find here the black walnut, the tulip tree, ash and others, elsewhere restricted to the alluvial "bottoms," on the ridges themselves, from sixty to a hundred feet above the stream beds.

Mississippi Bottom.—At the western foot of this bluff there lies the great Mississippi Bottom, with its rich soils and varied forest growth. This also, however, subdivides into at least three distinct soil and vegetative zones, viz., the sandy "Frontlands," which lie on the immediate banks of the great river and its main branches, and the heavy clayey "Back-land" areas, whose soils are partly the product of modern swamp deposits from backwaters, partly result from the disintegration of strongly calcareous clays constituting the lower part of the Bluff or Loess formation. A third natural subdivision is the "Dogwood ridge," a narrow belt of slightly elevated land, mostly above ordinary overflows, which extends diagonally from the Mississippi river to the Yazoo bottom, and seems to be the continuation of "Crowleys ridge" in Arkansas. Each of these soil belts has its own characteristic forest growth, as indicated in the table below the map.

We have here along an east-and-west line of about 200 miles, eleven markedly distinct zones of vegetation, readily recognized as such by every farmer, and each underlaid by a distinct geological terrane. It does seem as though a close study of these and of the soils overlying them should lead to some definite results showing the physico-chemical causes of these differences.

Lime apparently a governing Factor.—The connection of some of these changes in vegetation with the calcareous nature of the corresponding formation has already been referred to. As regards four of the eleven divisions, this is obvious even to the casual observer, and is well known to the population, who speak of the "lime country" or belts being, as a matter of common knowledge, the best land; in full accord with what, in Kentucky and elsewhere, has passed into a popular maxim.[1]

Taking as a guide the trees and plants which characterize the obviously calcareous lands, our next step should be to verify, if possible, the fact that wherever these occur naturally, lime is abundant in the soil in comparison with those lands in which such vegetation does not occur naturally, or perhaps even fails to flourish when planted without special fertilization. This the writer has sought to do, first in connection with the survey work of the state of Mississippi, and subsequently in the wider field that has since come under his observation.

SOIL BELTS IN SOUTHERN MISSISSIPPI.

In Mississippi, the general conclusions derived from the observations made on the northern cross section, are corroborated many times over in other portions of the state. Aside from the cretaceous prairie region, there runs across the middle of the state a belt of varying width, of calcareous tertiary beds, which also give rise to more or less extensive tracts of "black prairie" lands, interspersed with non-calcareous, mostly sandy ridges, the lower slopes of which, influenced by the calcareous beds, bear an oak and hickory growth, while the higher portions have only pine, and usually remain uncultivated. Southward of this "central prairie" belt lies the long-leaf-pine forest area of the state, underlaid throughout by sandy, non-calcareous formations, with poor sandy soils, savé here and there in patches, which can be at once recognized by the replacement of the long-leaved pine by a vigorous oak growth; as is also the case where the pine area abuts against the calcareous "Cane Hills" on the west. The bottom soils of this region are largely "sour," and bear the gallberry (*Prinos glaber*), bay galls (*Persea carolina*), ti-ti (*Cliftonia monophylla*), candleberry (*Myrica cerifera*), various whortleberries, the pitcher plants (*Sarracenia*), yellow star grass (*Aletris*), sundews, *Xyris, Eriocaulon,* and other plants of similar habits.

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[1] "A lime country is a rich country."

Vegetative and Soil Features of the Mississippi Coast Belt. —South of the long-leaf pine area lie the coast flats, with sour, sandy soils underlaid by stiff clays. On these "pine meadows" of the Mississippi coast occur some of the most striking cases of modifications of vegetation due to physical and chemical causes.

As is well known, the long-leaved pine habitually belongs to the dry sandy uplands of the Gulf States; the deciduous cypress, on the other hand, is most characteristic of the swamps, where its roots are permanently submerged in water. But on the pine meadows of the Mississippi coast we see these two incongruous trees growing side by side, though sadly worsted by their mutual concessions; their heights usually ranging from 12 to 15, rarely as much as 18 feet.[1] Yet both preserve their characteristic forms, the cypress being an exact miniature reproduction of the usual level-topped swamp form, except as to the "knee" feature; while the pine differs only in stature from its giant brethren of the pine hills, from which it can be traced down through all grades of transition. The soil on which this growth occurs is a sour, sandy one, one and a half to three feet in depth, underlaid by a solid, impervious gray clay, above which is usually found several inches of coffee-colored bottom water, which drains slowly into the sluggish water-courses, themselves carrying brownish, sour, but very clear waters. Analysis shows the soil to be sour and extremely poor, especially in its lime and phosphates (see chapter 19, p. 352); its

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[1] R. M. Harper, who has graphically described the vegetative features of the coastal plain of Georgia (Contr. from the Dep. of Bot. Colum. Univ. Nos. 192, 215, 216, 1902–05; also Bull. Torr. Bot. Club 29–32), claims the deciduous cypress of the wet pine-barrens and ponds therein, the vegetation of which greatly resembles that of the pine meadows of the Mississippi seacoast, to be a distinct species, *Taxodium imbricarium*, the leaves of which are imbricated, instead of two-ranked and with spreading leaflets. He supports this distinction mainly by the differences in habit from the Louisiana swamp cypress, and the fact that the imbricated form occurs wholly on non-calcareous land, while the other is at home in the calcareous alluvial areas. The imbricated form has been observed and commented on before, as a mere ecological variation, and in the writer's opinion this is all that can be claimed, in view of the much greater differences in the form of other trees, notably oaks, illustrated below, caused also by lime. There would, *à fortiori*, be reason for claiming at least three different species of post oak and black-jack (and two of willow oak), which differ not only in tree form but also in the form and number of leaf lobes, and yet can be traced into one another by innumerable transition forms. If new species are to be established on such grounds, it is hard to see where the variations manifestly due to environment are to come in.

herbaceous vegetation consists exclusively of very small-seeded, "calcifuge" plants (sedges, orchids, Juncus, Hæmodoraceæ, Xyris, Polygala, etc.). This land is wholly unproductive and affords but indifferent pasturage, except the first season after burning-over; probably because of the effect of the minute amount of ashes so added. As the coast is approached, the clay subsoil has an increasing depth of sandy soil-mass above it, and on these "sand hammocks" the long-leaved pine gradually assumes more and more of its usual stature; the cypress disappears, and the Cuban pine (here called pitch pine) gradually comes in; while the sedgy vegetation diminishes and finally disappears. On this land crops may be grown as in the long-leaf-pine uplands.

But on the immediate coast, evidently under the influence of the aboriginal "shell mounds," the yellow sandy soil becomes blackish from the (humus-forming) effect of the lime thus supplied; and concurrently the coast liveoak (*Q. virens*), grape vines, the Hercules club (*Aralia spinosa*), "l'herbe a trois quarts" (*Verbesina* sp.), and numerous leguminous plants (which are wholly absent from the pine meadows) take possession of the land, which is very productive and has been specially utilized in the growing of Sea Island cotton. Here the clay stratum is 15 to 20 feet below the surface, and roots penetrate to great depths in the pervious soil, whose great thickness makes up for its low percentage of plant-food (see table below). This land is distinctly limited by the extent of the shell heaps, past or present, and shows a respectable percentage of lime.

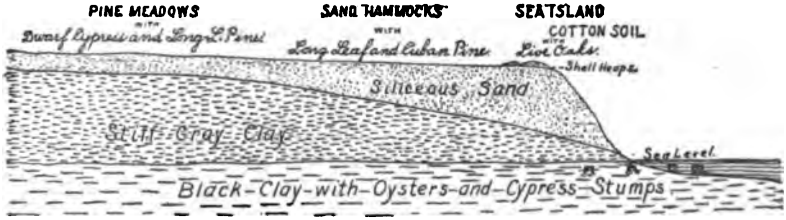

FIG. 78.—Schematic profile of the Mississippi Coast Belt, through Jackson County.

The annexed schematic profile (fig. 78) illustrates these changes of soil and vegetation, which furnish a striking example of the effective modification of vegetative features by physical and chemical soil-conditions.

It would be difficult to find a more striking exemplification of the effect of lime carbonate, not only upon the vegetation but also upon the physical and chemical characters of the hopelessly unproductive soil of the sand hammocks and pine meadows; no longer brown and sour, but jet black and neutral, modifying favorably every physical quality. Humus likewise nowhere shows its benefits more strikingly.

Table of Lime-Percentages.—The table below shows the average lime percentages observed in most of the several vegetative areas mentioned above. To meet the objection sometimes made that the vegetative changes noted may be due to the larger amounts of phosphoric acid and potash frequently found in calcareous lands, the percentages of the latter are also given. Considering the origin of limestones, such a connection is not unexpected, but it is far from constant. On the contrary, the frequent co-occurrence of much lime and high production with small percentages of phosphoric acid and potash leads to the conclusion, already discussed (see chapter 19, p. 365), that in presence of abundance of calcic carbonate, smaller percentages of phosphoric acid may be considered adequate than when lime is deficient, on account of greater availability. Almost the same may be said of potash; and it is quite possible that the presence of large amounts of lime tends to prevent the leaching-out of this base, in consequence of greater facility for the formation of zeolites. Illustrations of this kind have already been given (chapters 3, 22).

Definition of "Calcareous Soils."—It will be noted that the very obvious and important changes of vegetation are brought about by comparatively slight differences in lime-content. In fact, only two of the soils enumerated above would, according to the estimates usually given in books on soil composition, be considered as properly calcareous. But the decisive feature in this matter must evidently be the ***native vegetation***, which expresses the nature of the land much more clearly and authoritatively than any arbitrary definition or nomenclature can possibly claim to do. ***A soil must be considered as being calcareous whenever it naturally supports the vegetation characteristic of calcareous soils.***

TABLE SHOWING NATIVE FOREST GROWTH, POPULAR ESTIMATE OF DURABILITY AND INITIAL PRODUCTION, AND PERCENTAGES OF LIME, PHOSPHORIC ACID AND POTASH, IN MISSISSIPPI LANDS.

No.	Name.	Natural Vegetation.	Production Per Acre.	Physical Character.	K_2O.	CaO.	MgO.	P_2O_5.	Humus.
172	Black Prairie Soil.	Mainly sturdy black-jack and post oak, red cedar, crab apple and honey locust.	400 lbs. cotton lint, decreasing to 200 lbs. in 30 years.	Heavy, adhesive dark-colored clay.	.333	1.367	.363	.104	1.25
164	Pale Yellow Ridge Loam.	Scarlet, post and Spanish oak, small.	200 lbs. cotton first year, falling off to 75 to 100 lbs. by 5th year.	Pale yellow sandy loam.	.093	.069	.126	.033	[1] .50
226	Pontotoc Ridge Soil.	Oak, hickory, walnut, sweet and black gum, honey locust.	350—400 lbs. cotton lint, 300 lbs. after 20 years.	"Mulatto" medium loam.	.374	.281	.234	.082	1.00
230	Heavy Flatwood Soil.	Post and black-jack oak, and some short-leaved pine.	20 bushels of corn first year—then nubbins only.	Heavy gray clay.	.753	.178	.831	.052	.305
345	Black-Jack Ridge Soil.	Black-jack oak, pine, huckleberry.	Unproductive.	Very sandy loam.	.073	.142	.100	Trace.	[1] .20
142	Oak and Pine Upland Loam.	Red and post oak, pig-nut hickory, short-leaved pine.	200 lbs. cotton lint at first; 100 lbs. after 6—8 years.	Medium loam.	.236	.092	.196	.091	[1] .50
219	Brown Table-Land Soil.	Black, post, Spanish and black-jack oak, hickory, sweet and black gum.	400 lbs. cotton—250 lbs. after 20 years.	Clay loam.	.630	.270	.450	.210	.79
237	Bluff or Loess Soil.	Cane, black and white oak, tulip tree, linden, sassafras.	400 lbs. cotton, decreasing to 250 lbs. after 30 years.	Sandy loam.	.511	5.921	3.278	.143	.72
390	"Buckshot" Soil.	Hickory, ash, sweet gum, pecan, cow oak, honey locust, cane, crab apple, plum.	800 lbs. cotton lint, reduced to 500 lbs. in 30 years cultivation.	Heavy calcareous clay soil.	1.104	1.349	1.665	.304	[1] 1.0
206	Pine Hill Soil.	Long-leaved pine, with scattered small scarlet and post oak, and occasional pig-nut hickory.	20—30 bushels corn for one year—then nubbins. Usually good sweet potatoes for 2—3 years.	Light sandy loam; mere sand at 3 feet.	.259	.129	.180	.030	.35
215	Pine Meadow Soil.	Dwarf long-leaved pine, cypress, sedges, orchids, Hæmodoraceæ, etc.	Unproductive. Bears small-seeded, "sour" vegetation.	Very sandy loam, gray clay subsoil.	.061	.023	.069	.021	....
88	Shell Hammock Soil.	Live and water oak, cedar, magnolia, holly, dogwood, sweet gum, hickory, sassafras, grape, Hercules club, etc.	300 lbs. sea-island cotton for 15 years.	Very sandy loam, deep.	.080	.115	.065	.107	.75

[1] Approximate.

DIFFERENCES IN THE FORM AND DEVELOPMENT OF TREES.[1]

It will be noted that in the above table, as well as in the discussion preceding it, identical species of trees are ascribed to vegetative areas of widely different productive capacity. Perhaps the most striking example is that the cretaceous prairies and the adjoining flatwoods belt, standing respectively highest and lowest in the scale of productiveness, are yet bearing specifically identical tree-growth, to-wit, the post oak (*Quercus minor*) and the black-jack oak (*Q. marylandica*). While to the field botanist[2] there can be no question as to the absolute specific identity of the two trees as growing on the respective areas, yet the mode of development of both is so different in the two cases, that, as before remarked they are popularly supposed to be different "kinds."

Forms of the Post Oak.—The post oak of the prairie lands is a tree 50 to 70 feet high, with a stout, excurrent, rather conical trunk, often somewhat curved to one side above, and densely clothed from within 12 or 15 feet of the ground with comparatively short, sturdy branches set squarely to the trunk, much crooked (geniculate), often reflexed downward; altogether forming a dense head, beneath whose thick foliage, a bird or squirrel is quite secure from the hunter's aim.—In the flatwoods, on the contrary, the post oak has a thin, rather short trunk, divided up at 15 or 20 feet height into long, rod-like branches, spreading broom-fashion, and scantily clothed with

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[1] It is a matter of regret to the writer that owing to the long distance intervening and the difficulty of securing competent and sympathetic observers for such work, it has not been possible for him to secure photographs of the tree-forms here discussed. At the time his own observations were made, photography was practically unavailable as yet, and the figures given are therefore based upon sketches made at the time, and partly upon recollection. They represent types rather than definite individuals, which were however described when fresh in mind, in the Report on the Agriculture and Geology of Mississippi, 1860, pages 254 et seq.

[2] It has been already, and doubtless will be again and increasingly, attempted to make distinct "species" of these widely different forms of trees. But this is simply begging the question. Mere external diagnostic marks will not avail here; it would have to be shown that the seed of these different forms do not produce the other forms under changed conditions. Until this has been done, the numberless transition forms which he that runs may observe in the field, throw upon the species-makers the onus of proof of differences of specific value—if it be possible to define such value.

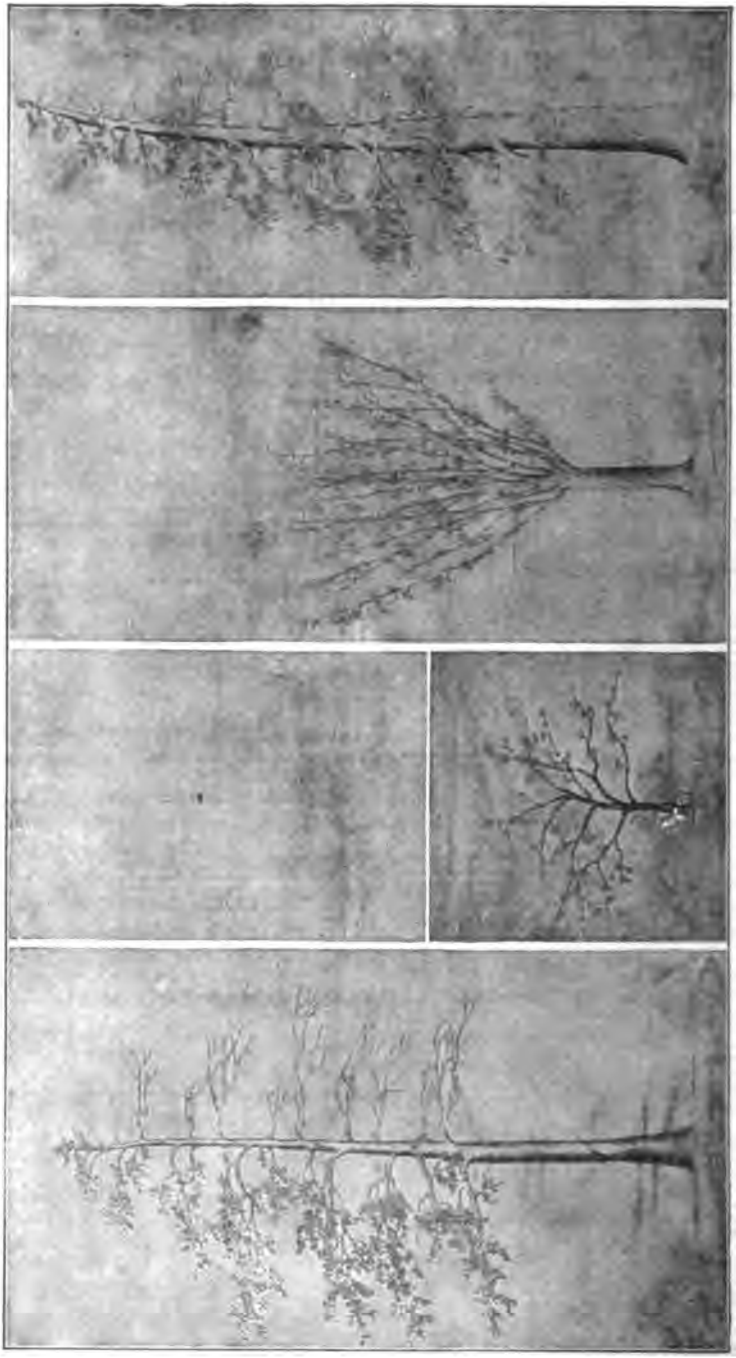
short twigs bearing tufts of leaves; thus forming an open head, in which no creature can hide effectually. On the brown-loam table-lands, again, the post oak has a straight, rather slender, excurrent trunk with long and more or less crooked limbs projecting at a large angle, sometimes even drooping, and freely divided up into lateral, leafy branches; the trees attain from 40 to 55 feet in height. Again, on the high sandy ridges which are interspersed in the eastern portion of the brown loam area, we find, generally associated with a similarly depauperated form of the black-jack oak, and with the Upland Willow oak (*Q. cinerea*), a form of the post oak intermediate between that of the Flatwoods and the Table lands; twelve to fifteen feet high, with thin trunk, " sprangling " long, crooked branches, clothed with sparse tufts of leaves. These four strikingly distinct types are shown schematically, in their extreme development, in the subjoined figures.

It is hardly necessary to say that between these extreme forms there are many degrees of transition, corresponding to the transitions between the several soil-classes respectively represented by them; or they may be developed into depauperated types. Thus, for example, the forms of the post and black-jack oak found on the sandy ridges of the yellow loam region, hardly need experience in the observer to interpret them as characterizing a wretchedly poor soil.

Forms of the Black-jack Oak.—Not less striking are the characteristics of the forms of the *black-jack oak* as developed upon these several kinds of land. The black-jack of the prairies is a low tree with a dense rounded head, often somewhat flattened above, and a low, thick-set trunk divided up into square-set branches, so densely clad with foliage that no light penetrates into the interior, and birds can safely hide and nest within it. The height rarely exceeds 35 feet, the head being 20 to 30 feet across.

The Flatwoods form, on the contrary, rarely exceeds 15 feet in height, with a very rough bark and a small, rather dense, rounded top, giving the whole the appearance of a small apple tree. Practically the same form is seen on poor, clay ridges of " hogwallow " land.

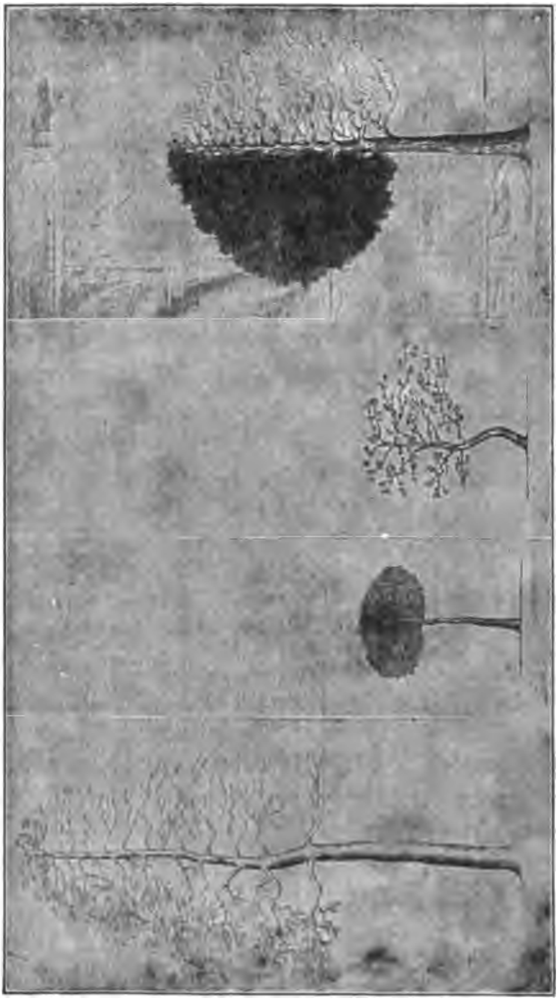
On the brown-loam lands the black-jack, like the post oak, has a rather slender, often somewhat crooked, but excurrent



Loam Upland. Sandy Ridges. Flatwoods. Black Prairie

FIG. 79.—Extreme Forms of Post Oak (*Quercus minor Marsh., obtusiloba* Mich).

trunk 35 to 50 feet high, with more or less crooked limbs of moderate length, well provided with leafy branches, but forming altogether a rather open crown. A depauperated form of this type occurs on the sandy ridges of the yellow-loam region and is 12 to 15 feet high, with slender, crooked branches, clothed with scanty foliage; as shown in Figure No. 80, alongside of the other typical forms.



Loam Upland. Flatwoods. Sandy Ridges. Black Prairie.

FIG. 80.—Extreme Forms of Black-Jack Oak (*Q. marylandica Mursh, nigra Wangh*).

In all these variations of the tree forms, there is also a concomitant variation in the forms and other characters of the leaves. Thus in the compact forms of the black-jack oak, the trilobate leaf is almost completely obliterated, the leaf being simply rounded-cuneate, somewhat auriculate at base. In the sparse-branched upland forms the leaves are deeply three-lobed, and the ferruginous tomentum of the lower surface is much less pronounced. The lobation of the post oak also varies considerably both in the numbers of lobes and in their obtuseness. Similar differences prevail in the case of the black and Spanish oaks; thus in the latter, the long terminal, falcate lobe is always most pronounced on " rich " soils, while on poor ones the trilobate leaf predominates.

Of course all these forms may be found bearing acorns, so that they undoubtedly represent adult trees.

Characteristic Forms of other Oaks.—Similar general features are repeated in the case of the other species of oaks, and also more or less in other kinds of trees; though mostly less pronouncedly than with the two species above described. Among the more striking are the two forms of the willow oak (*Q. phellos*), which on low, undrained ground assumes the low, rounded, "apple-tree" form, while on well-drained uplands of good fertility it is a beautiful, slender tree producing almost the effect of the acacia type; it is then a sign of first-class land. The scarlet oak rather reverses these types; on good, " brown-loam " upland it is of rounded form, not very tall, with sturdy, rough-barked trunk; while on poor hillside lands its tall, smooth, white trunk stands out as a conspicuous admonition to the landseeker to beware of a poor purchase. The black and Spanish oaks also indicate, by tall thin trunks, a deterioration of the land as compared with the lower and more sturdy growth on areas relatively richer in lime.

Sturdy Growth on Calcareous Lands.—One feature invariably repeated, not only in Mississippi but throughout the United States, is that *in many strongly calcareous soils the growth of all trees, as well as of shrubs and of many herbaceous plants, is of a more sturdy and thick-set habit* than that of the same species grown on thin, sandy, or generally on non-calcareous land. This effect is quite as apparent in the arid region of the Pacific Coast as in the Atlantic States, on the prairies of the Middle West, and of the Gulf Coast. The experienced farmer recognizes this habit of the tree-growth as a sign of good land, and the reverse, viz., trees of lank, tall and thin growth, as evidence to the contrary, from the Atlantic to the Pacific.

Cotton Plant.—The cotton plant affords very striking evidences of this influence of lime. On the bottom lands of a creek in Rankin county, Mississippi, the writer found a "patch" of cotton with luxuriant stalks reaching above the head of a man on horseback, but almost devoid of "squares" or blooms. The soil was very dark and rich-looking, but was derived from a non-calcareous tertiary terrane surrounding the heads of the stream. A few rods below, the latter crosses the line of a calcareous terrane, from which copious marly debris have been washed down on the bottom soil. Here the cotton was just half as high as above, and thickly covered with squares, blooms, and bolls.

Another similar example was noted on the Chickasawhay river, in Wayne county, Miss. Where that stream flows through the non-calcareous, lignitiferous area of the tertiary formation, its bottom lands bear cotton crops of medium productiveness only, the stalks being of the usual height of about three feet, and only fairly bolled. But a short distance below the point where the soft marls of the marine tertiary are cut into by the stream, the cotton plants on the bottom lands are from 18 to 20 inches high only, closely branched, and literally thronged with cotton bolls, so that the fields appear a solid mass of white. The only objection urged against this land is that to pick such cotton "breaks the backs" of the pickers. The tree growth of the bottom, of course shows a corresponding change.

Lime Favors Fruiting.—In connection with the obvious changes of form and stature caused by the presence of an abundant supply of lime carbonate in soils, there is another that has been long noted in cultivation, but is no less striking in the native vegetation. The abundant fruiting of oaks on such lands as compared with the same species on non-calcareous soils is a matter of common note in the Mississippi

Valley states; and the same is true of other trees, and of herbaceous plants as well. The fruit on the lime soils is often smaller, unless much humus is present; but the statement made in Europe that cultivated fruits, and especially grapes, are sweeter on calcareous lands, is abundantly verified in the native fruits of the Mississippi Valley states as well; where the various wild berries, haws, plums, etc., are well known to the younger part of the population to be much sweeter and higher-flavored in certain (calcareous) localities than in others, besides being usually more abundant.

This is entirely in accord with the well-known fact that the application of lime checks the excessive wood and leaf growth resulting from excess of nitrogen as well as moisture; while on the other hand, the injurious effects of overdressing with lime or marl are known to be repressed by the use of stable manure, or by green-manuring. The repression of excessive wood growth by lime would seem to offer a simple explanation of the compact habit of growth on calcareous lands; and the extraordinary sweetness of fruits grown in the arid region as compared with the same in the humid, is fully in accord with the high lime-content of the arid lands.

Stunted Growth.—In practice it will be found in most cases that a stunted native growth is due not so much to lack of plant-food in the soil, as to unfavorable physical conditions. Among these, *shallowness, and extreme heaviness* of the soil are the most common causes. The " scab lands," underlaid by impervious rock at a depth too slight for culture plants, as in many plateaus of the Pacific Northwest, and in rocky or mountainous regions generally, are cases in point. Strata of impervious clay often produce the same result; but in this case, should such clay be intrinsically capable of supporting plant growth, the land can often be made available for orchard purposes by blasting with dynamite (see chapter 10, p. 181).

The post oak (and black-jack) flats of the Mississippi Valley states are familiar examples of land whose dwarfed tree growth causes it to be avoided by settlers; similarly, a dwarfed growth of red elm (*Ulmus rubra*), hackberry and ash indicates in the flood plain of the Red river of Louisiana a heavy " waxy " red clay, or " gumbo " land, scarcely available for agricultural purposes.[1] The gray or white "crayfishy" bottom and bench lands of the Southwestern States, so poor in lime, phosphates and humus as to be worthless under existing conditions, are characterized by an easily recognized scrubby growth of Water and Willow Oaks (*Q. nigra,* or *aquatica,* and *phellos*), with low, rounded tops; while the same trees, when well developed, indicate highly productive lands.

Physical vs. *Chemical Causes of Vegetative Features.*—The extent to which the modifications of form alluded to above are referable to chemical and physical causes respectively, can be approached by the discussion of the presence or absence of certain trees from soils of extreme physical character, but otherwise normally constituted. As has been shown above, the black-jack and post oaks belong, as species, equally to the heaviest and lightest soils within the state of Mississippi; to the black and yellow "prairie" soils, as well as to the sandy ridges of the yellow-loam region; showing for these two species as such, an independence of physical conditions and an extraordinary adaptability, found in few other trees. They are frequently found either alone or associated with only a few other species of local adaptation, such as, in the prairie lands, the crab-apple, wild plum, and the juniper or red cedar. On the soils of intermediate or loam character, on the contrary, they are always associated with other oaks as well as with hickory, and in that association attain what may be considered their normal type or form.

From the fact that the dense, rounded top is formed by the black-jack oak both on the rich prairie lands and on the poor soils of the Flatwoods, it would seem that that form is the outcome of a physical cause, viz, the extreme "heavy-clay" character of both kinds of land; and we may note that exactly the the reverse effect is observed in the form growing on the poor sandy ridges, as shown in fig's 79 and 80. Yet it will also be noted that in the case of the post oak, the poor, heavy-clay soil of the Flatwoods produces an open, broom-shaped top, while the form assumed on the sandy ridges is substantially the same for both species. Care must therefore be exercised in drawing general conclusions as to the effects produced by either physical or chemical causes, *alone,* upon tree forms.

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[1] Rep. of Geological Reconnoissance of Louisiana; New Orleans, 1873, p. 27.

Lowland Tree Growth.—The variations occurring in the valleys or alluvial bottoms are less obvious to superficial observation, yet equally important and cogent to the close observer. In the properly alluvial lands, one dominant condition, that of *adequate moisture* supply, is almost always fulfilled, irrespective of soil quality. In addition to this, as stated in chapter 2 (see page 24), practically all the alluvial lands of the humid region may be considered as being of a more or less *calcareous* character, as compared with the adjacent uplands. These two important conditions dominate in a great measure the minor ones of variation in soil-texture. Yet where, as is largely the case in the southern part of the State of Mississippi, the amount of calcic carbonate is insufficient to overcome the sourness of the soil, the vegetative contrasts become extremely striking and characteristic, as explained above.

Contrast Between "First" and "Second" Bottoms.—A very striking phase of transition between the alluvial bottoms and the uplands proper in the Cotton States are the second bottoms or hammocks of the streams, whose soil and tree-growth in most cases differ markedly from those of the first bottom; and these being usually closely adjacent, often afford a very striking contrast to the latter. From some antecedent geological cause not fully understood, these hammocks, usually elevated from 4 to 10 feet above the present flood plain, have almost throughout soils of a fine sandy, pulverulent or silty nature, frequently in strong contrast to heavy clay soils in the first bottom.

They seem, moreover, to have been at some time subject to prolonged maceration under water, resulting in the reduction of the ferric oxid, and its accumulation in the lower portion of the deposit in the form of bog-ore spots or "black gravel." Since such a process always results in the abstraction of phosphoric acid from the general mass of the soil, to be accumulated in the bog ore in an inert condition,[1] these hammock soils, usually whitish or gray in color, are almost throughout poor in phosphates as well as in lime; the latter having been definitively leached out. The resulting vegetation, as may be imagined, is widely different from that of the bottom proper,

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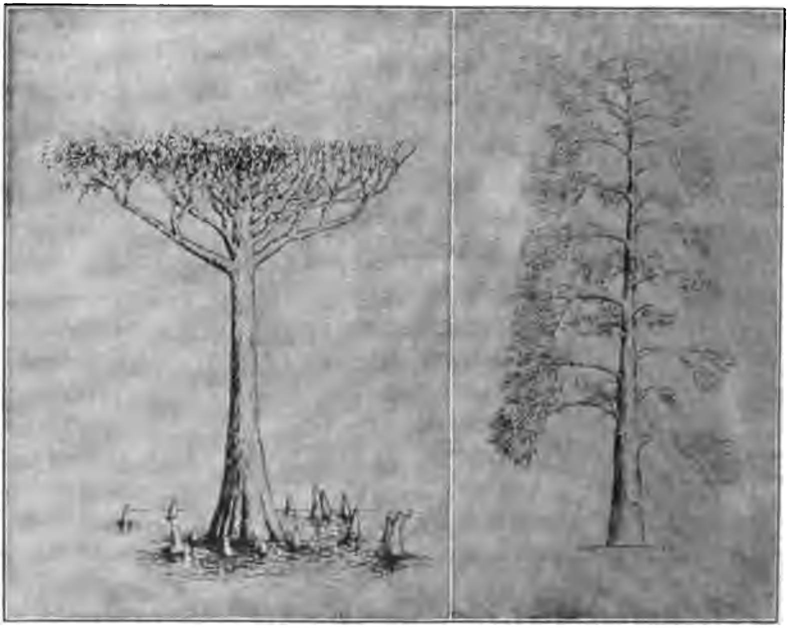
[1] See Chapter 2, p. 24.

as well as, frequently, from that of the adjacent uplands; and though level and fair to see, these hammocks are usually unthrifty and last but a short time under exhaustive cultivation. Accordingly, their forest growth is prevalently that of the poorer class of uplands, viz., small-sized post and black-jack oaks, and in the low ground depauperated water oak, or less commonly willow oak, of the low, stunted type indicative of a a soil of inferior productiveness. The luxuriant growth of the present alluvial bottom is often seen within a few feet of the unthrifty vegetation of these hammocks. It is usually only in the limestone regions, and in the lower course of the larger streams, that the hammocks or second bottoms are found to be of good fertility.

The Tree Growth of the First Bottoms. The Cypress.—Among the trees occupying the low ground of the first bottom in the southern Mississippi states, the deciduous cypress (*Taxodium distichum*) deserves special mention as an example of extreme variation in form. In sloughs and swampy tracts, as is well known, the cypress grows with roots submerged throughout the season, excepting only the excrescences known as "knees," which project above the water, probably performing some function in connection with the aeration of the root, which is essential to the root functions in all plants. The trunk rising from the water is supported by numerous projecting buttresses for from 8 to 15 feet above the water; higher up it becomes cylindrical for a height of from 40 to 70 feet, then divides up into a few widely spreading, thick, almost conical branches, whose twigs and foliage form an almost level surface to the head. This level-topped forest growth characterizes at once the submerged areas of the river and coast swamps.

But the cypress is by no means confined to the swamps and sloughs; it is also found occupying the better class of hammock lands, 12 or 15 feet above water level. In this case, however, the tree assumes a shape and growth so wholly different from that described above as to lead to a popular assertion of a difference of species. As a matter of fact, however, the cones of these upland cypresses, when dropping into the water below them, reproduce exactly the common swamp form. The extraordinary difference in the aspect of the tree under these different conditions is best seen in the subjoined diagram, showing the upland cypress to assume the form of the tall willow oak, with which it is sometimes locally associated.

The trees from which the annexed sketch is taken grew within thirty feet of each other, on Yellow creek, a small tributary of the Tennessee river, in Tishomingo county, Miss. The soil stratum is underlaid by a shaly limestone, and bears lime vegetation.



Swamp. Upland.

FIG. 81.—Forms of Deciduous Cypress on overflowed and on bench-land.

The fact that the deciduous cypress grows without difficulty on the moister class of lowlands in California, 12 or 15 feet above bottom water, is of interest in this connection. It then assumes the upland form shown in the figure above, although not growing quite as tall. The calcareous nature of these soils is probably an important factor in this apparently incongruous adaptation of a subtropical swamp tree to arid conditions. In its swamp form the cypress usually grows in rather shallow, heavy clay soil, into the dense subsoil of which the roots penetrate but little.

Other Lowland Trees.—The lowland hickories, like their brethren on the highlands, seem on the whole to prefer the lighter or loamy bottom soils to those of a heavier character. This is especially true of the Pecan. The latter, as well as the shell-bark hickory, is especially indicative of the highest class of bottom soils. The black walnut, while apparently also best suited in loamy soils, is also more or less found on heavy bottom lands, provided they are sufficiently calcareous; and the same is measurably true of the tulip or white-wood tree. The most frequent occupants of heavy bottom lands, however, are the black gum and sweet gum, so that "gum swamps" are usually found to be of that character.[1] But in the prairie region, where the bottom soils are very calcareous and heavy, as well as in corresponding soils of the "buck-shot" lands of the great Mississippi Bottom, the chestnut-white (cow- or basket-) oak sometimes occupies such ground almost exclusively. Among the accompanying trees are especially the honey locust, the crab-apple, mulberry and sweet gum, as well as ash.

General Forecasts of Soil Quality in Forest Lands.—While the oaks and pines mentioned as forming the bulk of the timber constitute in the cotton states the *primà faciè* evidence, as it were, of the general character of the land, there are numerous other trees and plants which serve the discriminating landseeker as a guide for the quality of the soils in different localities. While everywhere, well-developed black, red, Spanish and white oaks are considered as signs of a high quality of land, the tall, thin scarlet, the upland willow, and the barrens scrub oak are considered as indications detracting materially from the producing value wherever they prevail. The various hickories are throughout considered as indicating good land when mixed with the oaks, or by themselves; while the presence of walnut, linden and tulip tree will usually raise the estimate of uplands to the highest class. On the other hand, the occurrence of small black-gum trees and short-leaved pine, with low huckleberry, among the oaks of whatever kind, ac-

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[1] Hence perhaps the vernacular name "gumbo" for heavy, adhesive clay soils in the north central states; which may also, however, be derived from a comparison with the "gummy" pods of the cultivated okra or gumbo plant.

companied as they usually are by the disappearance of the black, white and Spanish oaks, will materially depress the land-values.

The appearance of well-formed oaks, as well as of hickory, is therefore at once welcomed as an evidence of soil improvement, while that of low huckleberry bushes and small black gums indicates the reverse. An increase in the thickness and retentiveness of the soil stratum is also usually indicated by the occurrence of short-leaved pine in the long-leaf-pine areas.

The black, red, white, and Spanish oaks belong altogether to soils of medium physical constitution, only their *size* upon such lands depending upon the relative richness in plant-food; but without such changes producing any notable variation in their *form*. Clearly then, these species are intolerant of extreme physical conditions, and are practically restricted to soils of "loamy" character and easy cultivation.

CHAPTER XXV.

RECOGNITION OF THE CHARACTER OF SOILS FROM THEIR NATIVE VEGETATION. UNITED STATES AT LARGE. EUROPE.

THE application of the above data outside of Mississippi can mostly be verified only in a fragmentary way from such data as are casually given in the reports of State Surveys, as well as from such observations as the writer has been able to make personally elsewhere. In the latter category the most copious refer to the states of Alabama, Louisiana and Illinois.

ALABAMA.—The observations of Prof. Eugene A. Smith, and those of Dr. Chas. Mohr, are especially valuable and cogent as to the close correspondence of the soil and vegetative phenomena with those observed in Mississippi,[1] They are faithfully reproduced on the corresponding geological areas, including also the Flatwoods. Northwest of Mobile, on the Mississippi line, the long-leaf-pine forest is interspersed with more or less continuous areas bearing a fine oak growth, with hickories and other trees indicating a calcareous soil. This feature is most extensively developed in Alabama in what is known as the " lime-sink region," on the borders of which the vegetative transition in passing from the non-calcareous sandy pine land, can be observed in the most striking manner and with frequent alternations. Northward of the long-leaf-pine belt, the tertiary and cretaceous areas show in Alabama the same features as in Mississippi, viz., black calcareous prairies alternating with ridge lands, among which in the cretaceous area the Pontotoc ridge is represented by a series of isolated knobs, popularly known as Chunnenugga ridge, closely resembling the former in its soils and vegetative character.

In northern Alabama, according to Dr. Smith, on the various stages of the Carboniferous formation, ranging from a

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[1] See Plant Life of Alabama, by Charles Mohr, Vol. VI. Contr. U. S. Nat. Herb., U. S. Dep't Agr.; Alabama Ed. of Same, Ala. Geol. Survey, 1901.

sandy or conglomerate character to that of limestones of various degrees of purity, soils contrast strikingly with each other, agreeing closely with those seen in the neighboring part of Mississippi. Here, moreover, the contrast between the natural vegetative character as well as cultural value of the lands derived from the magnesian limestones (the "barrens") contrasts strikingly with those originating in the purer limestones, on which the blue grass is at home.

LOUISIANA.—As to Louisiana, whose geological formations correspond closely to those of Mississippi, it may be said in general that the vegetative phenomena coincide completely with those observed in Mississippi. The "white-lime country" of northeastern Mississippi is represented in Louisiana only by patches occurring here and there on a line laid from Lake Bistineau to the coast at Petite Anse Island. But the chief characteristics of the calcareous area, among them especially that of the occurrence of red cedar and clumps of crab-apple, persistently reappear. The "Central Prairie Region" of Louisiana is quite narrow, but on it there reappear precisely the same characteristics described in connection with that area in Mississippi. In the long-leaf-pine region of Louisiana there occur, as in Mississippi, some isolated patches of a calcareous character, the largest of which is on the Bayou Anacoco in Vernon Parish, near the western border of the State. As we emerge from the sandy lands of the long-leaf pine area to that underlaid by the calcareous formation, we find, first, a change to oak and short-leaved pine, then the oak forest alone; finally, on a level black prairie of considerable extent, the post and black-jack oak in their thick-set form, clumps of crab-apple, red haw and honey locust, here and there a red cedar; exactly as has already been described in connection with the prairie lands of Mississippi. To southward of the long-leaf-pine area lies a broad belt of level, generally treeless, sandy prairie, in part dotted with groves of timber, but otherwise with nearly the same peculiar, small-seeded herbaceous vegetation observed in the corresponding portion of Mississippi. But in Louisiana there intervenes between these gray sour lands and the shell hammocks of the immediate seacoast with their groves of live oak, a belt of black calcareous prairie, increasing in width and clayeyness towards the West, and acquiring considerable extension in the corresponding portion of Texas. On these prairies we again find the calciphile vegetation, including the honey locust, clumps of crab apple and red haw, etc., but not usually any oak growth, except (near the seacoast) the live oak. In the hilly country of northern Louisiana there is reproduced substantially the vegetative character of the "short-leaf pine and oak" uplands of Mississippi (see map on p. 490, chapter 24), save in that, owing to the occasional outcropping of the calcareous materials of the Tertiary, small prairies with black soil are spotted about here and there. Bordering the Mississippi Bottom there are a series of oak-upland ridges with a brown loam soil corresponding to the fertile area in northwestern Mississippi, with small patches of the "Cane hills" loess soils, bearing a corresponding tree growth.[1]

In *Western Tennessee* the vegetative zones so distinctly shown in the adjacent portion of Mississippi are not so strikingly outlined, but so far as they do exist, the phenomena observed accord exactly with those heretofore described. The same holds true of *Western Kentucky*, as is well set forth and graphically described in the reports of the geological surveys of that state by Dr. David Dale Owen, and later by Dr. R. H. Loughridge.

North Central States.—North of the Ohio River the materials of the geological formations are not nearly as much varied as they are south of the same; consequently the vegetative features are also much more uniform. It must be remembered that from the Alleghenies nearly to the Mississippi, the states of Ohio, Southern Michigan, Indiana and Illinois are largely covered by drift deposits overlying the older formations, except that along the Ohio and Mississippi rivers lies the calcareous loam of the Loess or Bluff formation.

Within the states mentioned, however, not only are the older underlying formations very generally calcareous, but calcareous sand and gravel form a large proportion of the drift deposits, which in most cases overlie the rocks. Hence we find from the Alleghenies to the Mississippi a predominance of the oak forests which characterizes calcareous soils, as in the better class of uplands in Mississippi and Tennessee; interrupted

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[1] See "Final Report of a Geological Reconnoisssance of Louisiana," published by the New Orleans Academy of Science in 1871.

only here and there by sandy belts or ridges bearing inferior growth, among which, again, the black-jack and post oaks, with short-leaved pine, are conspicuous. But in a large portion of Illinois, as well as in Western Indiana, the oak forest is interrupted by more or less continuous belts, and sometimes by a wide expanse, of black prairie, generally treeless or bearing only clumps of crab-apple and haw, and underlaid more or less directly by the carboniferous limestones, whose disintegration has materially contributed to the black prairie soils; which are noted for their high and long-continued productiveness. The lower ground is characterized, besides clumps of crab-apple and red haw, by the frequent occurrence of the honey locust, the lead plant (*Amorpha fruticosa*), the button-bush (*Cephalanthus occidentalis*), and among herbs by the polar plant (*Silphium laciniatum*), the prairie burdock (*S. terebinthinaceum*), the swamp rose-mallow (*Hibiscus moscheutos*), the sneezewort (*Helenium autumnale*), the wild indigo (*Baptisia tinctoria* and *leucophæa*).

The black-jack and post oak are not nearly as frequently found on the prairies of Illinois as on those of Mississippi and Alabama; but where they occur they assume a similar habit, including the occurrence of the dwarfed, apple-tree-shaped form on the low ridges with heavy yellow clay soil, that sometimes intersect the prairies. The post oak, moreover, in a form quite similar to that described as occurring on the Flatwoods of Mississippi, forms the timber of the " post oak flats " occasionally found between the low ridges bordering the streams, or along the edges of the prairies. The herbaceous vegetation of these post oak flats distinctly characterizes them as being poor in lime. In the loamy uplands, where the calcareous ingredient is more abundant, the open-headed form of the black-jack and post oak are also found, interspersed with a luxuriant growth of black, red and white oak, with more or less of hickory, which here assume a magnificent development, much superior to that seen south of the Ohio. These yellow-loam uplands correspond very closely in their soil-composition and agricultural character to the brown-loam area of Mississippi and Tennessee, which lies inland from the Loess belt. Where these uplands approach the prairie or the outcrops of a limestone formation, there is usually added to the oak growth the linden, the wild cherry and the ash; the latter two also usually appear in the bottoms of the streams and on the slopes adjacent, together with the walnut and butternut, and in the lowest ground the sycamore.

The tree growth of the Loess belt bordering the Ohio and Mississippi, so far as climatic differences permit, agrees almost precisely with that described in the corresponding portions of Mississippi and Tennessee. The change from the oak and hickory growth covering the yellow-loam uplands toward the more calcareous area is evidenced by the appearance of large sturdy trees of sassafras, together with the linden and sugar maple. Descending from the "bluff" toward the rich bottom-prairie with its black, heavy soil, we at once encounter the familiar indices of the more highly calcareous land, viz., the honey locust, clumps of crab apple and red haw, with hackberry, Kentucky coffee tree and mulberry on the lower ground; In late summer and during autumn, a tall growth of the iron weed (*Vernonia*), several *Eupatoriums* (*E. perfoliatum* and *purpureum,* the white and the purple boneset) and of the blue-spiked *Verbena* are very characteristic, as are also several species of *Cassia* (Carolina coffee, etc.,) and the swamp rose-mallow.

Upland and Lowland Vegetation in the Arid and Humid Regions.—In the humid countries there is commonly a marked difference between the vegetation of the uplands and lowlands, arising not merely from the difference in the moisture supply, but evidently of a specific nature. When we discuss the characteristic plants in detail, it becomes obvious that it is *lime* vegetation that, in most cases, forms the characteristic differences between upland and lowland forest growth; a natural consequence of the leaching-down of the lime from the higher land to the lower levels. By way of counter-proof we find that when the uplands themselves are of a calcareous nature, a part at least of the lowland flora ascends into them. As prominent examples may be mentioned the Tulip tree (*Liriodendron*), black walnut, ash, Kentucky coffee tree, Hercules' club, etc., which are lowland trees over the greater part of their area of occurrence; but in the loess or Cane hills bordering the Mississippi and its larger tributaries, as well as in the limestone regions of the southwestern and western states, are conspicuous in the uplands as well. The tall southern cane (*Arundinaria macrosperma*), usually considered a plant of the low river bottoms, originally covered the loess or " Cane hills " of the lower Mississippi, with their highly calcareous soils. The same is true of many other trees and shrubs characterizing limy lands. Of course there are some whose habitat is dependent upon the concurrent presence of *both* lime and moisture, such as the sycamore, cottonwood, hackberry, pawpaw, etc., which are naturally found only in stream bottoms or on low hammocks.

In the arid region, on the contrary, the main difference in upland and lowland vegetation is (outside of mountain influences) entirely referable to moisture-conditions; the proof being that so soon as the uplands are irrigated the lowland flora takes possession. Both uplands and lowlands being abundantly calcareous, there then is no cause for any material differences. This substantial uniformity of upland and lowland plant growth is particularly striking in the comparatively restricted floras of Eastern Oregon and Washington, and in Montana, where the more luxuriant growth of the valleys is almost the only contrast seen when their vegetation is compared with that of the uplands adjacent.

Forms of Deciduous Trees in the Arid Regions.—Since, as shown above, the soils of the arid regions are almost throughout calcareous, we should expect that the forms of the native trees would in general conform to the rule given above. As regards the deciduous trees this is very generally true: We rarely see on the Pacific slope, south of Oregon, anything to compare with the tall oaks of the Atlantic forests. The native oaks are as a rule of low, spreading growth, with stout, short trunks; and as they rarely form dense forests, the timbered areas have an orchard-like appearance, characteristic of the landscapes of the arid region, from the Mezquit Plains of Texas to Eastern Oregon and Washington. Only where a very abundant supply of moisture prevails do we find occasional exceptions. The trees of the humid region when transplanted to California have a perverse tendency to branch low, so that only the most persistent trimming-up will induce them to form trunks at all like those found in their native climes. In some cases no amount of trimming will result in the formation of anything more than bushes.

It may be objected that the arid climate as such, and not the calcareous nature of the soil, is the cause of this tendency. It is unquestionable that this low-branching habit is a distinct advantage to the plants, whose trunks would otherwise be frequently scorched by the hot summer sun; as happens when Eastern settlers try to grow "standard" fruit trees, with the result that a "sore," or sunburnt streak is formed on the southwest side of the exposed trunk. All orchard trees should therefore be pruned "vase-shape" in arid climates, partly for this, partly for other reasons. But this cannot explain the fact that seedlings from eastern acorns act precisely as do acclimated trees; so that it is not a case of the survival of the fittest to endure arid conditions.

Tall Growths of Conifers. Moreover, while the rule holds good with almost all deciduous trees, it is not applicable to the Conifers; which in the case of the Sequoias (redwoods and "big-trees"), sugar pine and others, exemplify some of the tallest growths known in the world. The Eastern Cedar or Juniper grows tall only on sufficiently calcareous soils, and in the Mississippi Valley states at least, wherever it occurs is an unfailing indication of calcareous lands. The extended occurrence of the spruce on the Allegheny Ranges, where limestone formations prevail so largely, seems to indicate a similar preference for calcareous lands. And this is certainly true of the black locust, which reaches its extreme southern range in the cretaceous hills of Northeastern Mississippi, showing the stout, stocky form it also assumes when planted in the calcareous black-prairie lands of Illinois.

Herbaceous Plants as Soil Indicators. While herbaceous plants are not as generally considered by land-seekers in judging of soil fertility and character, it goes without saying that very many are quite as characteristic as the tree vegetation, especially when deep-rooting, so as not to indicate merely the character of a few inches of surface soil.

In the Middle West of the United States especially, a large number of the Compositæ serve as marks of high productive capacity. This is particularly true of the larger species of the sunflower tribe, among which *Helianthus grosse-serratus* and *doronicoides* are perhaps the most generally notable; while farther west, beginning with Kansas, the "Sunflower State," and its northern neighbor, *H. annuus,* whether native or introduced, becomes conspicuous also. The *Silphiums* (compass sunflowers) have nearly the same significance, *S. laciniatum* and *perfoliatum* being prominent on the prairies of Illinois and Indiana; but in land under cultivation they are mostly replaced by a luxuriant growth of the Ragweed, *Ambrosia trifida.* Various species of *Bidens* (beggar ticks), notably the *B. aristata* and *cernua,* accompany the true sunflowers in the lower grounds of these regions, as do also *Heliopsis laevis, Coreopsis triperis* and *Rudbeckia* (*Obeliscaria*) *pinnata. Rudbeckia hirta* and *purpurea,* though also occurring on rich soils, are not characteristic of them. The larger species of golden rods (*Solidago*), notably *S. canadensis, rigida* and *speciosa* (not ordinarily distinguished by farmers) share substantially the distribution of the large sunflowers mentioned above. Of the Asters, only *A. novæ-angliæ* serves as a reliable guide to high-class lands in the Middle West,[1] but a very copious growth of asters and solidago of various species is always a welcome indication of land quality, and indicates soils of good lime content, if not absolutely calcareous.

Leguminous Plants.—It is generally understood that most leguminous plants, and among them especially the clovers, indicate rich, or rather, calcareous lands. The very large proportion of lime contained in the ash of legumes at once creates this presumption, which is fully confirmed by experience so far as our ordinary culture plants of that relationship are concerned. The favoring effect of lime on the development of bacteria, so essential to the full development of cultivated legumes, has already been referred to. The favoring effect of gypsum sown even in small amounts with clover and other legumes, may probably be referable to the known action of that salt in promoting nitrification, which in the first stages of leguminous growth is so highly favorable to a vigorous and early start of the crop, and to a more copious production of the nitrogen-assimilating nodules. The quick change noted in meadows and pastures of languishing production so soon as moderately limed, by the appearance of clover among the herb-

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[1] In view of its specific designation and the reputed poverty of New England soils, this is rather unexpected.

age, at once reminds us that the Rhizobia do not flourish in acid lands. The great prevalence of leguminous plants of all kinds in the arid region—clovers (not fewer than twenty-three species in California alone), Lupins, Astragalus and related genera, at once remind us of the universal prevalence of calcareous soils in these regions, as shown above. *Mutatis mutandis,* we find precisely the same general facts in the arid regions of the other continents.

Nevertheless, it must be kept in mind that not all plants of the leguminous order are positively " calciphile." Within the United States, it is especially the genera *Desmodium* (*Meibomia*) and *Lespedeza,* which are very numerously represented in the long-leaf pine region of Mississippi, where the soils are so poor in lime. Whether under these conditions these plants develop the rhizobian nodules, has not, so far as the writer is aware, been definitely observed. Certain it is that quite a number of these plants occur on both calcareous and non-calcareous soils, and on the latter assume a much more vigorous development than in the pine woods. But it is evident that they, with a few others (*e. g. Galactia mollis, Cassia chamæcrista* and *nictitans*) are more or less *indifferent* to the lime-content of soils, and cannot therefore be relied upon in judging the quality of lands. In Mississippi and northern Alabama, the *Tephrosia virginica* (" devil's shoestring "), associated with chestnut and short-leaved pine, is characteristic of the poorest non-calcareous lands, and bears seeds but very scantily. It disappears so soon as calcareous lands are approached, together with the chestnut tree.

EUROPEAN OBSERVATIONS AND VIEWS ON PLANT DISTRIBUTION AND ITS CONTROLLING CAUSES.

The writer has thus far presented and discussed mainly his own observations made in the United States, without reference to the previous and contemporaneous work on the same subject in Europe. There arose certain discrepancies which could not well be explained without a previous full consideration of American conditions.

As is well known, for nearly twenty years the accepted theory in Europe was that of Thurman,[1] which attributes the

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[1] Essai de Phytostatique appliquée à la chaine du Jura et aux contrées voisines, 2 vols. 8vo. Berne, 1849.

distribution of the native floras entirely to physical conditions; thus anticipating by more than half a century the corresponding hypothesis lately brought forward by the U. S. Bureau of Soils. Thurmann classes plants simply as hydrophile and xerophile, thus differing from most of our modern ecologists merely in omitting the transition phase of "mesophytes," which now serves as a convenient pigeon-hole for an indefinite variety of plants.

While gradually many were led by their observations to doubt the correctness of Thurmann's exclusive physical theory, Fliche and Grandeau [1] were apparently the first to impair by their investigations the confidence in the accepted view. They investigated exhaustively the conditions under which the maritime pine and the chestnut tree, both antagonistic to lime, would flourish, and proved that the presence of any considerable amount of lime in the land would cause them to languish or die, although the physical conditions so far as ascertainable were exactly alike. It is interesting to note what were the lime-percentages which caused these differences; viz, for the "noncalcareous" soil and subsoil, respectively, .35 and .20%; for the calcareous land, 3.25 and 24.04%, the latter evidently being decidedly "marly." The composition of the ash of these trees is very instructive, and is therefore given in full. Alongside of the ash of the maritime pine on the two soils is given that of the Corsican pine, a lime-loving tree.

COMPOSITION OF PINE ASHES ON CALCAREOUS AND NON-CALCAREOUS LANDS.

	MARITIME PINE, PINUS PINASTER.		CORSICAN PINE, PINUS LARICIO.
	On non-calcareous soil.	On calcareous soil.	On calcareous soil.
Potash	16.04	4.95	13.56
Soda	1.91	2.52	2.24
Lime	40.20	56.15	49.13
Magnesia	20.09	18.80	13.49
Ferric Oxid	3.83	2.07	3.29
Silica	9.18	6.42	7.14
Phosphoric acid	9.00	9.14	11 33
Total	100.25	100.04	100.18
Ash per cent	1.32	1.54	2.45

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[1] Annales de Chimie et de Physique, 4me série, tome 29; ibid. 5me serie, Tome 2. Also, ibid, tome 18, 1879.

It is very interesting to note in these analyses the inverse ratio in the absorption of potash and lime by the maritime pine, which seems to be unable to defend itself against excessive absorption of lime and thus experiences a dearth of potash which naturally interferes with the formation of starch and chlorophyl; hence probably induces the chlorosis so well known to occur on excessively calcareous soils. The lime-loving Corsican pine takes up a larger total amount of ash and more phosphoric acid, and nearly three times as much potash, but considerably less lime than did the maritime pine on the same calcareous soil.

The corresponding analyses made by Fliche and Grandeau, of the leaves and wood of chestnut grown on the same two kinds of soils, gave in general the same results; and they add that the smaller content of iron absorbed by the calcifuge trees when grown on calcareous soil point also to a deleterious influence upon the normal formation of chlorophyl.

Following Fliche and Grandeau, Bonnier[1] made corroborative tests by sowing seeds of the same plants, both calciphile and calcifuge, upon the two kinds of soils, and noting the differences in their mode of growth and internal structure.

Calciphile, Calcifuge and Silicophile plants.

The subject has been somewhat exhaustively discussed by Contejean[2] who enumerates and has classified under the three general heads of calciphile, calcifuge and indifferent, over 1700 species of European plants. Unfortunately he had but few soil analyses at his disposal, and was inclined to consider as non-calcareous, most soils that gave no effervescence with acids. But notwithstanding this disadvantage so far as his contention of the efficacy of chemical soil-composition, and especially of lime is concerned, he disproves very effectually the physical theory of Thurmann, by numerous examples from France and elsewhere in Europe; and also disposes very definitely of the claim that there is a special class of "silicophile" plants. He concludes that silica (and sand) is merely a neutral and inert medium which offers refuge to the plants "expelled" by lime; and that clay similarly exerts no chemical but

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[1] Bull. de la Société Botanique de France, tome 26, 1879.

[2] Geographie botanique. Iufluence du terrain sur la vegetation. Baillère et et Fils, Paris, 1881, 143 pp.

only a purely physical action. That potash, phosphoric acid and nitrogen, while most essential as plant-foods, exert otherwise little if any effect on general plant-distribution. He alludes similarly to magnesia; and his final conclusion is that "chemical are in general more potent than physical influences," and that the most widely active influences are carbonate of lime and chlorid of sodium. He does not, of course, deny the potent influence of moisture upon plant distribution.

Since these publications were made, many observers have investigated the subject, and the broad distinction between lime-loving or calciphile and lime-repelled or calcifuge plants has been very generally recognized and discussed: but the cause of this discrimination by plants is still more or less the subject of controversy. Some still claim that the calcifuge plants (such as the chestnut, the huckleberries and whortleberries, the heather and many other Ericaceæ, most sedges, etc.) are repelled by calcareous lands because they need a large supply of silica, which they suppose cannot well be assimilated in presence of much lime; hence they also designate the calcifuge plants as "silicophile"; while others attribute the preference of calciphile plants to the physical effects produced upon the soil by lime, as outlined above (chapter 20, page 379).

The contention that the presence of much lime in soils renders silica insoluble and hence unassimilable by plants, is at once negatived by the fact that waters exceptionally rich in silica, partly simply dissolved by carbonic acid, partly in the form of water-soluble alkali-silicates, are very abundantly found in the arid region. This is especially the case in California, where moreover a number of species of very rough-surfaced horsetail rushes and grasses prove the ready absorption of silica when wanted, even in strongly calcareous soils. But the question is whether the supposed class of silicophile plants is a reality or merely a theoretical fiction, based upon the habit of speaking of "siliceous" soils as a class apart from other and especially heavier or clay soils. As a matter of fact, the siliceous soils usually so called are simply those poor in clay and lime—in other words, "light" lands, the outcome of the weathering of quartzose rocks into sandy soils, which in the humid region are always poor in lime because thoroughly leached. In the arid region, on the contrary, sandy lands are quite commonly just as calcareous as the heavier soils, and show no "silicophile" flora.

According to the writer's observations and views, it being obvious that some plants are practically indifferent to the presence or absence of lime in the soil except in so far as it influences favorably the physical conditions, *moisture* must always stand first as the condition of maximum crop production, and as a *conditio sine qua non* of the best development of plants on all kinds of soils; its best measure being a matter of special adaptation to each species. But this being understood, he agrees with Contejean as to the commanding influence of lime in determining the adaptation of soils to plants, both cultivated and wild. At the same time, it is obvious that the absence of the opportunity to observe *really* native vegetation, adapted to the soils through ages, has created for European observers difficulties which are readily solved where original native floras are available.

Schimper[1] says pointedly that observations prove that the differences between the location of plants on calcareous and siliceous soils are not constant, but vary from province to province; that *e.* g., the list of indifferent (bodensteter) plants for the Alps do not hold good in the Dauphiné, still less between the Carpathians and Skandinavia. According to Wahlenberg the following species are calciphile in the Carpathians, and according to Christ indifferent in Switzerland: *Dryas octopetala, Saxifraga oppositifolia,* most of the leguminous species, *Gentiana nivalis, G. tenella, G. verna, Erica carnea, Chamæorchis alpina, Carex capillaris. Geum reptans* is reported by Bonnier to be exclusively calciphile on Mont Blanc, exclusively silicophile in the Dauphiné; indifferent in Switzerland. A great number of similar contradictions are reported by others as well, and the entire subject thus becomes rather vague; so that Schimper and others suggest that climatic conditions may in part be responsible for these discrepancies.

In all, or nearly all these cases, it is tacitly assumed that the underlying geological formation has essentially been the source of the soil, and that its character is determined accordingly. But this assumption is wholly arbitrary unless confirmed by actual direct examination. A soil-formation overlying

[1] Pflanzengeographie, p. 111 & ff.

limestone on the slopes of a range may be wholly derived from non-calcareous formations lying at a higher elevation, or may have been leached of its original lime-content by abundant rains. The feldspars constituting rocks designated as granite, may or may not be partially or wholly of the soda-lime instead of the potash series; the mica may or may not be partially replaced by hornblende, in which cases the soil would be calcareous to the extent of determining the character of the flora as calcifuge or calciphile, without its being at all evident in the physical character of the soil, which would still be " granitic " or " siliceous." Such observations in order to be critically decisive, clearly require that the observer should be, not merely a systematic botanist, nor a mere geologist or chemist, but all these combined. There is good reason to believe that most or all of these supposed contradictions would disappear before a critical physical and chemical examination of both the soils and the rocks from which they are supposed to have been derived. Contejean himself, in placing so many of his long catalogue of plants into the doubtful groups, suggests many cases in which the above considerations may explain the apparent discrepancies.

What is a calcareous soil? The definition adopted for this volume has been given in a previous chapter (chapter 19, page 367); viz, that *a soil must be considered calcareous so soon as it naturally supports a calciphile flora*—the " lime vegetation " so often referred to above and named in detail. Upon this basis it has been seen that some (sandy) soils containing only a little over one-tenth of one per cent. of lime show all the characters and advantages of calcareous soils; while in the case of heavy clay soils, as has been shown, the lime-percentage must rise to over one-half per cent. to produce native lime growth. While in the United States observations of the contrasts between calciphile and calcifuge floras are easily made in the field, and the facts must attract the attention of any fairly qualified observer, in Europe they would have to be made the subject of special cultural investigation based upon soil analysis; a procedure not yet fully accredited abroad, any more than in the United States. In a general way it has however been recognized by Mærcker, as shown at the end of the preceding chapter. How far this estimate was based upon American precedents, can now be only conjectured. Certain it is that the European definition of calcareous soils remains to the present day a wholly different one from that stated above; and from this have arisen the greater part of the doubts and differences of opinions among European botanists as to the classification of plants in relation to calcareous soils. Two per cent. of lime (equivalent to nearly double the amount of carbonate) is the prevailing European postulate for a calcareous soil. Some go so far as to postulate effervescence with acids, requiring about 5% of the carbonate.

Predominance of Calcareous Formations in Europe.—It is not generally recognized even among geologists how abnormally predominant are *limestone* formations in Europe. In all works on European agriculture we find the "lime sand" mentioned as a normal ingredient of soils, specially provided for (or against) in the operations of soil examination. Its presence is the rule, its absence the exception. Soils as poor in lime as are those of the long-leaf and short-leaf pine regions of the United States, are there very exceptional and (like the "Haideböden" of northern Germany) have long remained almost uncultivated. Calcareous soils being the rule in the regions of intense culture, the ideas of both agriculturists and agricultural chemists have in Europe, in the main, been based upon them as normal soils; so that instead of comparing calcareous, and non-calcareous soils properly speaking—*i. e.*, such as would not bear native lime-vegetation—the majority of comparisons has actually been made between soils which, in the American sense, were all or chiefly within the calcareous class. It is characteristic of this state of things that the injuriousness of an *excess* of lime is among the foremost themes of European (especially French and English) agricultural writers, as against the beneficent effects prominently assigned to lime in America. No such popular saying as that "a lime country is a rich country" exists in Europe; on the contrary, we constantly hear, and see in books, the mention of "poor chalk lands," and in France especially the deleterious effects of excess of lime upon crops is the theme of remark. Excess of lime in their marly lands has been the despair of French vintners, and Viala was specially sent to America to find some vine to serve as a grafting stock which would resist the tendency to chlorosis which renders many of the American phylloxera-resistant vines useless to the viticulturists of France. Viala did not find such grape-vines until he reached the cretaceous (chalk) area of Texas, where the native vines had long ago adapted themselves to marly soils; and these vines have solved the problem for French viticulture.

And England, France, Belgium and most of western Europe *are* rich countries, largely owing to their abundant limestone formations; and it may be questioned whether, had this been otherwise, Europe would so long have remained the center of civilization; for starving populations are not a good substratum for high mental culture and progress. It may equally be asked whether the invariably calcareous character of arid soils, as heretofore shown, has not, together with their general high quality, been largely a determining factor in the location and persistence of so many ancient civilizations in arid lands; as outlined in chapter 21, page 417. In this connection, the proper distinction between calcareous and non-calcareous soils passes from the domain of natural science to that of the history of human civilization.

CHAPTER XXVI.

THE VEGETATION OF SALINE AND ALKALI LANDS.

Marine Saline Lands.—While the saline alluvial lands of the sea-coast differ both in their mode of origin and in their nature from the alkali soils or "terrestrial saline lands," as they have been called in Europe, their vegetation has in many respects a common character. Not only is there much similarity, sometimes even identity, in the kinds of plants inhabiting these lands, but their saline ingredients induce certain changes of form and structure in plants not properly "saline" but more or less tolerant of soluble salts, by which the saline or alkali character of the lands may be recognized.

Just as in the case of lime we must distinguish between the plants definitely repelled by a large amount of this substance in the soil (calcifuge), while others prefer the soils in which lime is abundant (calciphile), and still others appear to be indifferent to its presence and are governed in their habitat by the physical conditions presented: so in the case of saline lands the salts may attract or repel certain plants. The latter class is much the largest; while there is also a number of plants which are more or less indifferent to the presence of salts, provided these be not in very great excess. Such plants constitute the next-largest class; while those attracted by salts, and whose welfare is conditioned upon their presence, are comparatively few in number, and still fewer among them are of economic importance. Hence the soluble salts have largely a negative importance for agriculture; the question usually being how to utilize the land until the undesirable surplus of salts can be got rid of, partially or wholly, as the case may be; the former usually in sea-shore lands, the latter in the alkali lands proper; in which a small remnant, not sufficient to injure crop plants, is usually desirable (see chapt. 23, p. 462).

General Character of Saline Vegetation.—Those familiar with seashore marshes cannot fail to note the fleshiness and succulence of the characteristic plants. This "incrassation" belongs not only to the saline flora proper, but is acquired to a greater or less degree when plants not ordinarily at home on saline ground are transferred to it artificially, or by saline overflows; while at the same time the leaves usually become smaller, and the growth more compact. Correspondingly, when saline plants are transferred to non-saline ground, the leaves generally become thinner and larger, and the growth more slender. The well-known "Russian thistle" is a case in point, as is also its close relative, the soda saltwort (*Salsola soda*); although the latter does not often venture as far from the saline lands as does the former (*Salsola kali tragus*), which now seems to have become a world-wide weed, with only a shade of preference for alkali lands.

Structural and Functional Differences Caused by Saline Solutions.—It has been definitely shown by the investigations of Schimper, Brick, Hoffmann, Lesage, Rosenberg and others, that the peculiarities or changes of structure brought about by saline solutions are essentially those pertaining to xerophile (drought-enduring) vegetation; which in general tend to the diminution of evaporation from the plant surfaces. It may be said, roughly speaking, that the absorption of water by the roots begins to diminish so soon as the concentration of the saline solution approaches or exceeds one-half of one per cent; while when it rises as high as three per cent., water-absorption by the roots ceases even in the wettest soils, and the plant suffers from drought quite as much as from any directly injurious effects of the salts. Different plants of course differ in the measure of concentration which brings about these phenomena, which vary also with the character of the soluble salts. It is stated that injurious or useless salts like common salt act at lower concentrations than *e. g.*, saltpeter, which is useful. The difference in external structure are: diminution of the size of leaves, assumption of cylindrical or spinous forms, sinking-in of the breathing pores below the outer surface, dense hairy covering, resinous exudations, etc. Internally we find that xerophile plants have developed on their upper or outer leaf-surfaces instead of one, several layers of "palisade" (long and erect, closely-packed) cells, through which transpiration is extremely slow, as is also the transmission of heat. When salt-tolerant plants are grown on saline soils, their palisade cells are relatively lengthened.

Coincident with these external means for the retardation of evaporation, the leaves of xerophiles are frequently supplied with special water-storage cells, which supply moisture for the physiological processes when the root supply falls short. The cactus tribe and similar-looking plants are examples of the latter provision, which causes even animals suffering from thirst to resort to them, although they eschew the saline vegetation.

Absorption of the Salts.—The true halophytes or exclusive salt plants, which refuse to grow on lands not containing a large proportions of salt, often absorb so much salt that on drying it blooms out on their surface; they usually have, even when green, a distinctly salty taste, and their ash is rich in chlorids, specially of sodium. Such is the case of the samphire, common in saline marshes everywhere. The total ash is usually very high, often varying with the salinity of the water or soil in which they have grown. Thus the salt-content of the ash of samphire may vary by several per cent. In other cases, as in that of one of the Australian saltbushes investigated at the California station, neither the ash content nor the composition of the ash varies materially whether the plant be grown on strong alkali land, or on uplands whose total saline content does not exceed (in four feet depth) .015% or 2500 pounds per acre.

The following table gives the composition of the ash of this saltbush alongside of that of two other prominent alkali-plants of the same relationship, occurring, one in the San Joaquin valley of California, in strongly saline lands, the other in the Great Basin region of the interior, on lands strongly impregnated with carbonate of soda. All these, it will be seen, take up very large amounts of sodium salts, notably the chlorid; the Australian plant most so, the "greasewood" of the Great Basin least so; a large proportion of the alkali salts being evidently, in the latter case, contained in the form of organic salts, which in the ash become carbonates.

It will be noted that the saltbush hay contains nearly one-fifth of its (airdry) weight of ash, of which nearly 40% is common salt. It therefore has a distinctly salty taste, and is

ANALYSES

	OF ASHES OF SALINE AND ALKALI PLANTS.						OF FORAGE CROPS.		
	Australian Saltbush, Atriplex semibaccata.[1]	Bushy Samphire, Allenrolfea occidentalis.[1]	Greasewood,[2] Sarcobatus vermiculatus.	Saltgrass,[2] Distichlis spicata.	Tussock grass,[2] Sporobolus airoides.	Prickly Pear,[2] Opuntia macrocentra.	Shad scale,[2] Atriplex canescens.	Alfalfa Hay.[1] (Cal.)	Timothy Hay.
Ash, airdried plant, %.	19.37	12.03	13.81	11.61	7.99	24.18	4.23	9.85	6.15
Potash (K_2O)	11.42	18.53	30.11	3.30	5.78	1.61	25.17	43.72	28.80
Soda (Na_2O)	35.39	39.45	32.58	2.38	5.15	2.76	6.23	4.48	2.70
Lime (CaO)	5.75	1.36	8.70	5.25	8.05	65.66	25.97	20.51	9.83
Magnesia (MgO)	3.23	1.09	1.09	2.95	4.15	26.70	16.63	2.56	3.60
Br. ox. of Manganese (Mn_3O_4)	.22			.16	.25		.51		
Peroxid of Iron (Fe_2O_3) Alumina (Al_2O_3)	3.33	7.06	not det'd.	2.22	2.39	1.19	5.89	2.95	
Silica	16.24	11.81	4.00	78.73	66.79	.81	11.94	5.87	35.00
Phosphoric acid (P_2O_5)	2.80	3.51	5.60	.83	1.25	.47	3.11	5.00	10.80
Sulfuric acid (SO_3)	2.64	4.93	5.90	3.20	4.52	.64	4.93	6.92	3.90
Chlorin, per cent	24.33	15.30	11.00	1.40	2.13	.21	2.07	10.25	5.00
Totals	105.35	103.04	99.79	100.31	100.46	100.05	100.45	102.26	99.70
Less excess, O: Cl	5.35	3.25	2.50	.31	.46	.05	.45	22.6	1.13
True totals	100.00	99.79	97.29	100.00	100.00	100.00	100.00	100.00	98.57

[1] Jaffa, Cal. St'n Rept 1894–95, p. 169.

[2] Goss, New Mex. St'n Bull. No. 44; recalculated.

always moist to the touch, containing ordinarily over 15% of moisture. It is therefore much liked by stock when fed intermixed with other hay, and thus supplies all the salt needed by cattle. The greasewood is much less liked by stock, and bushy samphire is wholly rejected by them. Comparing with these fleshy plants the ash of the two grasses, the first a world-wide "salt grass," the other a common grass of the American arid region, we note that not only do they contain much less soluble ash than the saltbushes, but especially much smaller amounts of sodium salts; proving that even when growing in company with the saltbushes on strongly impregnated land, they can repel from absorption these to them useless or injurious salts. But in the case of the "shad scale," also a "saltbush" of the Great Basin, the ash-content is remarkably low—only about one-fifth of that of its Australian relative—and it differs widely from the latter in having but a very low proportion of soda, and a very high one of lime and potash, approaching in these respects to our usual forage crops; and being also fairly rich in nitrogen, it forms acceptable browsing when other pasture plants are scarce. It therefore does not exert the laxative action produced by the exclusive feeding on the more saline herbages.

The exceptionally high ash-content of the cactus or prickly pear, also given in the table, arises, it will be noted, not from the soluble salts but from the absorption of extraordinarily high proportions of lime and magnesia. Owing probably to the latter substance, and also the oxalate form in which lime is usually found in the cactus tribe, this plant when used as forage is also somewhat laxative.

Altogether, this table offers remarkable examples of wide differences in the kind and amount of ash ingredients absorbed by plants growing upon similar soils and under identical climatic conditions; indicating a selective power which no merely physical theory of soil-action in plant growth can explain.

Injury to Plants from the Various Salts.—The early observers, especially Contejean, were predisposed from their observations of lime on vegetation to ascribe the action of salt upon marine vegetation to the sodium component. But the wide differences in the effects of different sodium compounds, notably of common salt and Glaubers salt, led some to the conclusion that the acidic ingredients are the chief determining factors. Moreover, it was soon found that a single salt is more injurious than a mixture of several, such as sea water. This also led to the inference that the varying degree of dissociation of these salts essentially influences the effects.

Kearney and Cameron have investigated these relations,[1] and have by artificial cultures in solutions of varying concentration and composition studied the behavior of plant roots and the limits of their endurance. They found for the several salts occurring in alkali soils, taken separately, the following figures, in 100,000 parts of water:

Magnesium sulfate	7
" chlorid	12
Sodium carbonate	26
" sulfate	53
" chlorid	116
" bicarbonate	167
Calcium chlorid	1,377

It will be noted that in many respects the results given in this table stand in marked contrast to the facts observed in alkali lands everywhere; and therefore while interesting physiologically, are not directly applicable to practice. Magnesium sulfate, which according to this table is the most injurious of all, is a common ingredient of alkali lands from Wyoming to New Mexico, as also is sodium sulfate; yet there, as well as in the Musselshell valley in Montana, and at many other points, it shows no specially deleterious action either upon native or cultivated plants, and in Europe as well as in New England the mineral kieserite is freely used as a fertilizer at many points. That sodium sulfate should be twice as harmful as sodium chlorid or common salt, and half as harmful as the carbonate or black alkali, is again wholly contrary to actual experience, which as shown elsewhere in this chapter, indicates that the majority of plants will tolerate between three and four times as much of sodium sulfate as of common salt; while the ratio of tolerance as against the carbonate seems sometimes to rise as high as ten to one.

It is clearly evident, however, that it is the metallic or basic ingredient that in the main determines the toxicity of these salts. The universal presence of lime in some form in all alkali lands doubtless

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[1] Report No. 71, U. S. Dep't of Agriculture, 1902.

explains the discrepancies mentioned, since lime is especially potent in counteracting the injurious effects; thus throwing additional light upon the importance of the lime-content of alkali soils proper, and also upon the causes of the narrow limitations of the littoral (marine saline) flora; inasmuch as, unlike alkali soils, marine alluvial lands are by no means always calcareous. Cameron goes so far as to attribute the favorable effects of gypsum upon black alkali not so much to the conversion of the latter into neutral sulfate, as to the effect of gypsum solution in counteracting the saline effects. This interpretation, however, seems rather far-fetched, since there can be no question about the double decomposition of gypsum with carbonate of soda; or the intense injuriousness of carbonate of soda in the actual corrosion of vegetable tissues. The corresponding protective influence of various salts, more especially of those of lime, against the injurious effects of pure common salt on marine animals, has already been mentioned (chapter 20, page 380), and later investigations by Osterhout on marine algae, show the same relation to hold true for them also.

Reclamation of Marine Saline Lands for Culture.—The reclamation of sea-coast lands and marshes for agricultural use is based in general upon the same methods as those already outlined for alkali lands in chapter 20; except that in this case no chemical neutralization is possible, since common salt cannot be changed by any practically feasible means. It must be removed by leaching, and this, in the humid countries in which such reclamations have chiefly been made, is usually done by the agency of rains, aided by ditching. The "polder" lands thus reclaimed along the shores of the North Sea, from Belgium to Prussia, are especially esteemed for their productiveness, doubtless owing to the alluvium of the numerous rivers tributary to that sea, which is distributed along its shores and in the numerous inlets and bays. The tides are of course excluded by dikes provided with gates opening outward, so as to permit of the outflow of rain- or irrigation-water used for leaching purposes.

Out of reach of stream alluvium no exceptional fertility is to be expected of sea-shore lands, which then commonly assume the form of sand dunes or bars, incapable of nourishing any cultural vegetation. Of the latter, the groups listed below as tolerant of alkali salts, may also be considered with reference to reclaimed sea-shore lands; the first cereal to succeed being usually barley, the first root crop, beets. Asparagus is also available while salt is being leached out.

THE VEGETATION OF ALKALI LANDS.

The general character of alkali-land vegetation is not unlike that of saline sea-shore lands; some species of plants are common to both, but the alkali lands harbor a much greater variety of plants, owing to the differences in climates and soils as well as to the nature of the impregnating salts. Moreover, owing to the very causes which underlie the presence of these salts, viz, aridity, the xerophile or dry-land character of the alkali-land flora is much more pronounced than that of the saline sea-shore vegetation. In view of the very complex conditions, the discussion of the alkali-flora is of. necessity much more complex than that of the marine group; and the data for its full elucidation with respect to the nature of the soils and salts are as yet very incomplete.

RECLAIMABLE AND IRRECLAIMABLE ALKALI LANDS AS DISTINGUISHED BY THEIR NATURAL VEGETATION.

While, as shown above (chapter 20), the adaptation or non-adaptation of particular alkali lands to certain cultures may be determined by sampling the soil and subjecting the leachings to chemical analysis, it is obviously desirable that some other means, if possible available to the farmer himself, should be found to determine the reclaimability and adaptation of such lands for general or special cultures.

In alkali lands, as in others, the natural plant-growth affords such means, both as regards the quality and quantity of the saline ingredients. The most superficial observation shows that certain plants indicate extremely strong alkali lands where they occupy the ground alone; others indicate preeminently the presence of common salt; the presence or absence of still others form definite or probable indications of reclaimability or non-reclaimability. Many such characteristic plants are well known to and readily recognized by the farmers of the alkali districts. "Alkali weeds" are commonly spoken of almost everywhere; but the meaning of this term—*i. e.,* the kind of plant designated thereby—varies materially from place to place, according to climate as well as the quality of the soil. It is obvious that if these characteristic plants were definitely observed, described and named, while also ascertaining the amount and kind of alkali they indicate as existing in the land, lists could be formed for the several regions, which would indicate, in a manner intelligible to the farmer himself, the kind and degree of impregnation with which he would have to deal in the reclamation work; thus enabling him to go to work on the basis of his own judgment, without previous chemical examination.

A study of the lands of California having this purpose in view, was undertaken in the years 1898 and 1899 by the California Station; but lack of funds prevented its prosecution beyond the ascertainment of those plants the abundant occurrence of which prove the land to be irreclaimable without the use of the universal remedy, viz, underdrainage, which on the large scale is usually beyond the means of the land-seeker. The botanical field work and collection of soil samples was carried out by Mr. Jos. Burtt Davy; the chemical work, as heretofore, being done by Dr. R. H. Loughridge. The results here reported are therefore essentially their joint work. It is hoped that in the future, a more comprehensive study and close comparison of the native vegetation with the chemical determination of the quality and kind of alkali corresponding to certain plants, or groups of plants, naturally occurring on the land, may enable us to come to a sufficiently close estimate of the nature and capabilities of the latter from the native vegetation alone, or with the aid of test plants purposely grown, for the farmers' purposes.

Plants Indicating Irreclaimable Lands.—The plants hereinafter mentioned and figured are, then, to be understood as indicating, *whenever they occupy the ground as an abundant and luxuriant growth,* that such land is irreclaimable for ordinary crops, unless underdrained for the purpose of washing out surplus salts. The occurrence merely of scattered, more or less stunted individuals of these plants, while a sure indication of the *presence* of alkali salts, does not necessarily show that the land is irreclaimable.

The plants which may best serve as such indicators in California are the following:

Tussock-grass (*Sporobolus airoides* Torr.), Fig. 82.

Bushy Samphire (*Allenrolfea occidentalis* (Wats.) Ktze.), Fig. 83.

Dwarf Samphire (*Salicornia subterminalis* Parish, and other species), Fig. 84.

Saltwort (*Suaeda torreyana* Wats., and *S. suffrutescens,* Wats.), Fig. 85.

Greasewood (*Sarcobatus vermiculatus* (Hook.) Torr.), Fig. 86.

Alkali-heath (*Frankenia grandifolia campestris* Gray), Fig. 87.

Cressa (*Cressa truxillensis* Choisy), Fig. 88, perhaps identical with *C. cretica* auct.

Salt-grass (*Distichlis spicata*), Fig. 89.

TUSSOCK GRASS (*Sporobolus airoides,* Torr.); Fig. 82.
(" Buneh grass " of New Mexico).

The three sets of Tussock-grass soil which have been analyzed show that the total amount of all salts present is in no case less than 49,000 pounds per acre, to a depth of four feet; and that it sometimes reaches the extraordinarily high figure of 499,000 pounds. Of these amounts the neutral salts (Glauber's salt and common salt) are usually in the heaviest proportion (Glauber's salt, 19,600 to 323,000 pounds per acre; common salt, 3,500 to 172,800); the corrosive sal-soda varying from 3,000 to 44,000 pounds.—Tussock-grass apparently cannot persist in ground which is periodically flooded. It is of special importance because it is an acceptable forage for stock.

Tussock-grass is a prevalent alkali-indicator in the hot, arid portions of the interior, from the upper San Joaquin Valley, the Mojave desert, and southward; also through southern Nevada and Utah as far east as Kansas and Nebraska. In the San Joaquin Valley it has not been found farther north than the Tulare plains, although east of Reno it occurs near Reno. Coville observes that in the Death Valley region " it is confined principally to altitudes below 1,000 meters" (3,280 feet). Hillman, however, reports it from

FIG. 82 —Tussock Grass—*Sporobolus airoides* Torr.

near Reno, Nevada, at an altitude which cannot be much less than 4,500 feet.

The tussocks formed by this grass, which are unfortunately not shown in the figure, sometimes appear as veritable little grass trees, and when denuded by the browsing of cattle seem like trunks 18 and 20 inches high. It is therefore very easily recognized; but it should be noted that in view of the extraordinary range of its tolerance, shown above, its scattered occurrence does not necesarily indicate irreclaimable land.

BUSHY SAMPHIRE. (*Allenrolfea occidentalis* (Wats.) Ktze.) Fig. 83.

This plant is locally called greasewood, but as this name is much more commonly used for *Sarcobatus vermiculatus,* it seems best to call Allenrolfea "bushy samphire," as it closely resembles the true samphire (*Salicornia*).

Bushy Samphire usually grows in low sinks, in clay soil which in winter is excessively wet, and in summer becomes a "dry bog." Wherever the plant grows luxuriantly the salt content is invariably high, the total salts varying from 327,000 pounds per acre, to a depth of three feet, to 494,520 pounds in four feet. The salts consist mainly of Glauber's and common salts (a maximum of about 275,000 pounds each); salsoda varies from 2,360 to 4,800 pounds per acre. The percentage of common salt and total salts is higher than for any other plant investigated, and the content of Glauber's salt is also excessive. The areas over which this plant grows must therefore be considered among the most hopeless of alkali lands, for although its salts are "white," submergence during winter precludes the growth of Australian saltbushes. Full underdrainage alone could reclaim the soil-areas it occupies. Bushy Samphire is common on low-lying alkali lands in the upper San Joaquin Valley, California, and extends northward along the eastern slopes of the Coast Range to Suisun Bay. It is also abundant in the Death Valley region, apparently overlapping the southward range of the *Sarcobatus,* the greasewood properly so-called.

DWARF SAMPHIRE (*Salicornia subterminalis,* Parish, and other species of the interior); Fig. 84.

The three or four species of Dwarf Samphire which grow

FIG. 83.—Bushy Samphire—*Allenrolfea occidentalis* (S. Wats.) G. Ktze.

in the interior valleys of the State are not usually very abundant, save locally. Wherever the species do occur, however, they may be considered as indicating excessively saline soils.

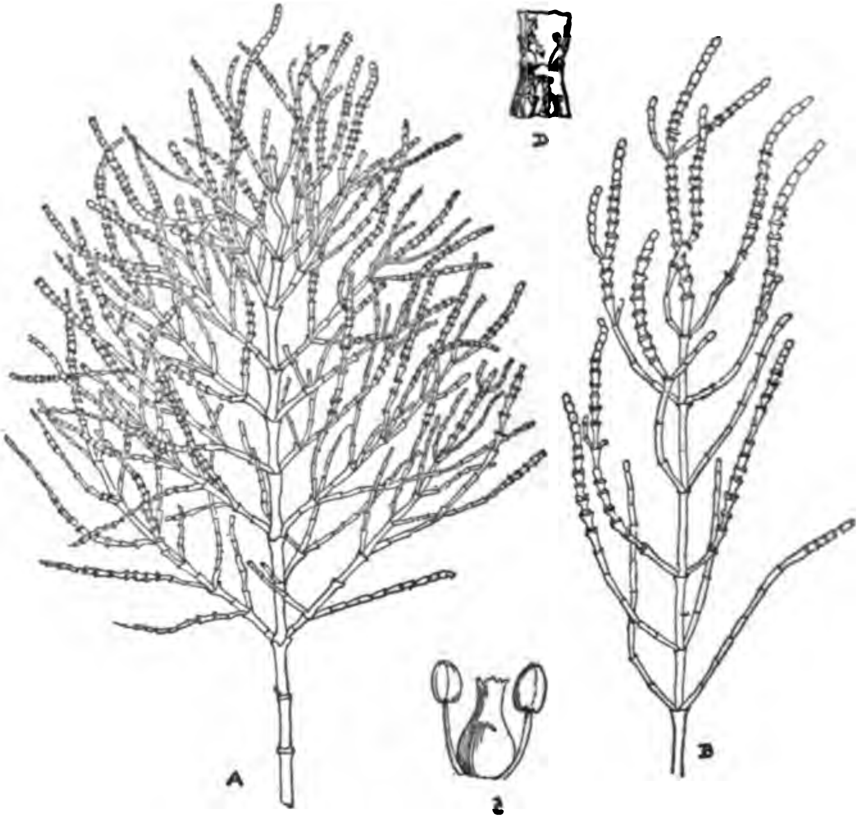

Fig. 84.—Salicornia subterminalis. Alkali samphire.

A. Much-branched form.

B. Slender form.

C. Flower with the perianth removed showing the simple pistil and the two stamens.

D. Portion of flowering spike, showing two joints. The flowers are impressed in the joints in opposite clusters of three. In each cluster the middle flower stands slightly above the two laterals as shown in the lower joint.

Dwarf Samphire soil has shown a total salt content of 441,880 pounds per acre in a depth of four feet. The neutral Glauber's salt amounts to 314,000 pounds, almost as much as in Tussock-grass soil; common salt up to 125,640 pounds while the salsoda varies from 2,200 to 12,000. We may consider the plant as indicative of almost the highest percentage of common salt, Glauber's salt and total salts. Like the preceding species it indicates land strongly charged with salts, more especially common salt, and susceptible to cultivation only after reclamation by under-drainage.

Salicornia subterminalis, S. herbacea (L.), *S. mucronata,* and another species, all occurring inland, differ materially in habit and botanical characters from the one so conspicuous in submerged salt marshes along the seashore; but all alike indicate strongly saline soils, reclaimable only by thorough drainage.

SALTWORT (*Suaeda torreyana,* Wats., *S. suffrutescens,* Wats., and perhaps one other species); Fig. 85.

Samples of saltwort soil from Bakersfield and Byron Springs, California, taken to a depth of one foot and three feet respectively, show that this plant grows luxuriantly in a soil containing 130,000 pounds of total salts per acre in the first foot, and with 10,480 pounds of the noxious salsoda, and 39,760 pounds of common salt in three feet; while only a sparse growth is found on soils containing only 3,700 pounds of salts in three feet. It thus appears to indicate a lower percentage of salsoda than does Greasewood, but a higher percentage than Bushy Samphire. Further investigation is necessary to determine the exact relation of the different salts to the growth of the plant, and as to whether carbonates occur in large quantity; but enough data have been gathered to show that a luxuriant growth of Suaeda torreyana indicates a soil reclaimable only by thorough-drainage.

Suaeda torreyana occurs on low alkali lands throughout the State of California, from San Bernardino to Honey Lake, in the desert sinks, and in the Great Valley, in appropriate locations. Sometimes it is replaced by *S. suffrutescens* and perhaps other species, but all the saltworts appear to grow in similar habitats, and it is probable that the soil-conditions are practically the same for all these species. They indicate land too heavily impregnated for the growth of ordinary crops, but which will perhaps allow the Australian saltbush to succeed.

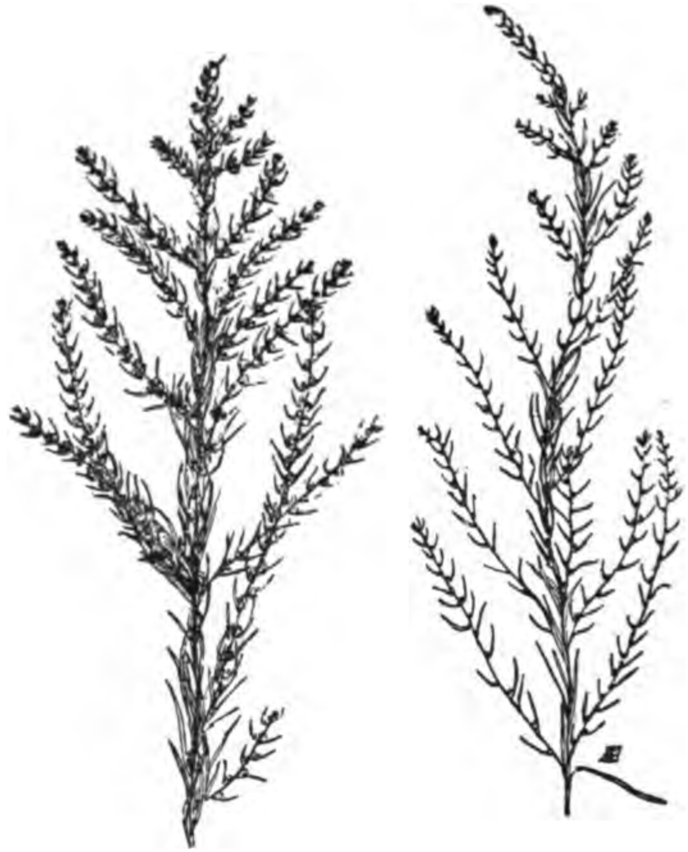

FIG. 85.—Saltwort—*Suaeda Torreyana*, Wats.

GREASEWOOD (*Sarcobatus vermiculatus* (Hook. Torr.); Fig. 86.

This, the true *Greasewood* of the desert region east of the Sierra Nevada, and not either of the plants known under that name in the San Joaquin Valley and in Southern California, invariably indicates a heavy impregnation of the land with black alkali or carbonate of soda. Since, as before stated, black alkali is most likely to occur in low ground, we frequently find the true greasewood forming bright green patches in the swales, and on the benches of periodic streams, as well as on the borders of alkali ponds or lakes. Stock unaccustomed to it will frequently go to these patches on a run, only to turn away badly disappointed after taking a few bites, the plant being both bitter and salty.

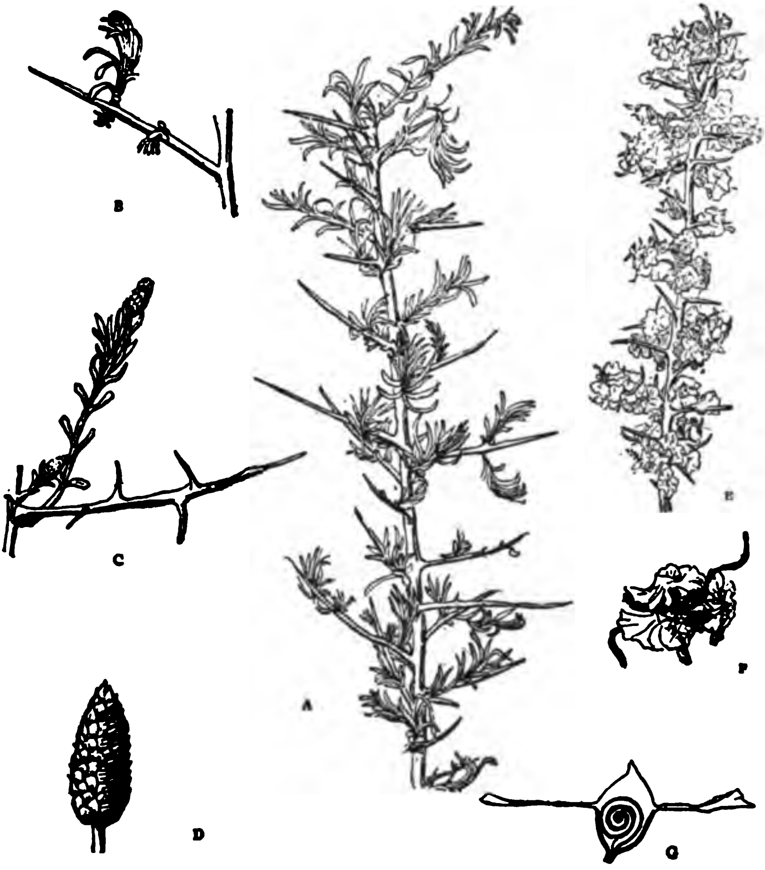

FIG. 86.—Greasewood (proper)—*Sarcobatus vermiculatus* (Hook) Torr.

A. Appearance of a branch when not in blossom.
B. Spiny-branchlet from the same.
C. Branchlet bearing cones of male flowers.
D. Cone of male flowers, enlarged.
E. Branch bearing fruits.
F. Cluster of fruits, enlarged.
G. Vertical section through a fruit, showing the seed with its curved embryo, (enlarged).

Where a luxuriant growth of this plant is found, the soil may contain from 38,000 to 117,000 pounds of total salts per acre, of which sometimes nearly half is carbonate of soda; the content of common salt is usually low, and Glauber's salt or sulfate of soda, sometimes with considerable proportion of epsom salt, forms a variable proportion of the total.

Greasewood is distinctly a plant of the Great Basin, only reaching California in the adjacent counties of Lassen, Alpine, Mono, and northern Inyo. It is very abundant on the lower levels of Honey Lake valley, Cal.

The Sarcobatus is chiefly found on silty or sandy soils of good native fertility (see page 445, chapter 22), so that when its excess of salsoda is neutralized by means of gypsum, the land becomes very productive. Unfortunately the cost of the amount of gypsum required to render such soils adapted to the tolerance of most culture plants is often prohibitive; but where the correction of only small spots is called for, the "white alkali" resulting from the gypsum treatment would be tolerated by many culture plants.

ALKALI-HEATH (*Frankenia grandifolia campestris* Gray); Fig. 87.

Fig. 87.—Alkali-Heath—*Frankenia grandifolia campestris* A Gray.

Alkali-heath is perhaps the most widely distributed of any of the California alkali plants. Its perennial, deep-rooting habit of growth, and flexible, somewhat wiry rootstock, which enables it to persist even in cultivated ground, render it a valuable plant as an alkali indicator. The salt-content where Alkali-heath grows luxuriantly is invariably high, ranging from 64,000 to 282,000 pounds per acre; salsoda varies from 680 to 19,590 pounds; common salt ranges from 5,000 to 10,000 pounds. Such soils would not be benefited by the application of gypsum, as the salts are already largely in the neutral state. Of useful plants only Saltbushes and Tussock-grass are likely to flourish in such lands, when not too wet.

While Alkali-heath is thus one of the most alkali-tolerant plants, it is at the same time capable of growth with a minimum of salts (total salts 3,700 pounds, salsoda 680 pounds). Where only a sparse growth of this plant occurs, therefore, the land should not be condemned until a chemical examination of the soil has been made.

Alkali-heath is found on soils of very varying physical texture and degrees of moisture; while on soils of uniform texture and moisture-conditions, but differing in chemical composition, it varies with the varying salt-content.

It has been found that Australian saltbush (*Atriplex semibaccata*) can be successfully grown on the "goose-lands," of the Sacramento Valley, on soil producing a medium crop of Alkali-heath; it remains to be shown whether it will do equally well on soils producing a dense and luxuriant growth of the same.

Alkali-heath is widely distributed throughout the interior valleys of California; a closely related form grows in the salt-marshes of the sea-coast.

CRESSA (*Cressa cretica truxillensis* Choisy); Fig. 88.

Cressa soils show a low percentage of the noxious salsoda, but comparatively heavy total salts (161,000 to 282,000 pounds per acre.) Common salt varies from 5,760 to 20,840 pounds per acre in four feet. The maximum is lower than in the case of Alkali-heath, but Cressa seems to be much more closely restricted to strong alkali than does the former species. Cressa appears to be as widely distributed through the interior valleys of California as Alkali-heath. The Cressa is a cosmopolitan plant, occurring, as its name indicates, on the Ionian Islands, as well as in North Africa, Syria, and other arid countries of the world.

SALT-GRASS, *Distichlis spicata.*—This grass is of world-wide distribution, and always indicates a sensible content of soluble salts, without apparently any special preference for either of the three most commonly occurring ones. Its maximum tolerance, as will be seen by the preceding table, is very high, yet at the same time it will grow luxuriantly on lands containing so little that other saline plants like the samphires, saltwort or greasewood will refuse to grow. On the shores of Honey Lake, California, it may often be seen incrusted with the salts of the water concentrated by a long season of drought, yet maintaining life, though somewhat stunted. On lands lightly impregnated, stock will often eat it quite freely, so that it has been mistaken for Bermuda grass, to which its habit and foliage bears some resemblance. But Bermuda grass, while not as sensitive to alkali as most forage grasses, will probably not bear much over 12,000 pounds per acre.

FIG. 88,—Cressa—*Cressa cretica truxillensis*, Choisy.

The mere *presence* of the salt grass cannot therefore be taken as a definite indication of anything more than that there is an unusual amount of salts in the soil; whether or not there

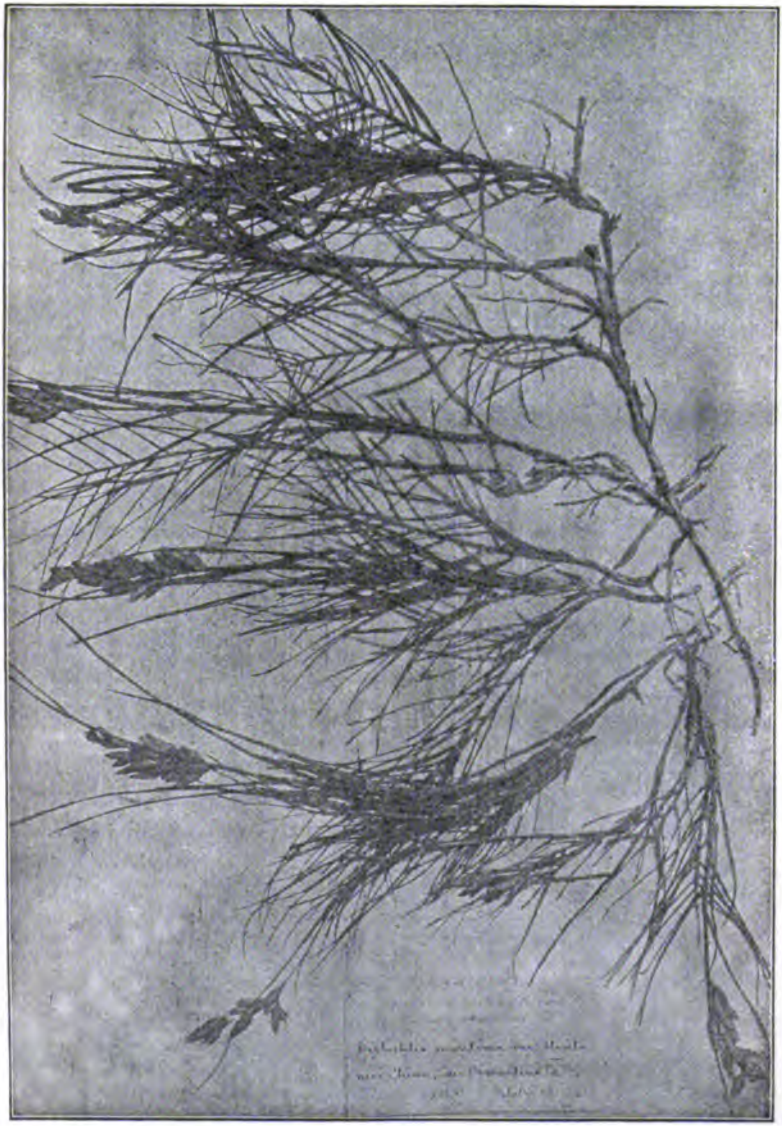

FIG. 89.—Salt-Grass—*Distichlis spicata* (L.) Greede.

is more than will be tolerated by the ordinary culture-plants, must be judged either from the accompanying plants, or by experiment or analysis.

Relative Tolerance of the Different Species.—The following table shows in systematic order the tolerance of the several plants discussed above, for the different salts, so far as the data available permit. The column marked *optimum* shows under what proportions of salts the plants grew in about equal luxuriance, therefore under, apparently, the most favorable conditions. Both above and below the proportions mentioned in that column, the luxuriance (size) and (usually) the abundance of the plants was less; showing that while excessive amounts of salts depressed their welfare, yet they also suffered when the proportions dropped below a certain point. Whether this was partly or wholly the result of competition with other plants, is an unsettled question.

TABLE SHOWING MAXIMUM, OPTIMUM, AND MINIMUM OF SALTS TOLERATED BY EACH OF THE SEVERAL ALKALI PLANTS.

	Pounds Per Acre in feet.		
	Optimum.	Maximum.	Minimum.
Total Salts.			
Bushy Samphire	494,320	494,520	135,060
Dwarf Samphires	441,880	441,880	441,880
Alkali-heath	281,960 64,300	499,040	3,720
Cressa	281,960	281,960	161,160
Saltworts	130,000	153,020	3,720
Greasewood	58,560	58,560	2,400
Tussock-grass	49,000	499,040	49,000
***Carbonate* (Salsoda).**			
Tussock-grass	23,000	44,460	3,040
Alkali-heath	*19,590 680	19,590	680
Greasewood	18,720	18,720	1,280
Dwarf Samphires	12,120	12,120	2,200
Saltworts	10,480	12,120	1,120
Cressa	5,440	5,440	680
Bushy Samphire	4,800	4,800	1,500
***Chloride* (Common Salt).**			
Bushy Samphire	212,080	275,160	56,800
Dwarf Samphires	125,640	125,640	125,640
Saltworts	39,760	52,900	1,040
Cressa	20,840	20,840	5,760
Alkali-heath	10,180 5,760	212,080	1,040
Tussock-grass	6,200	172,800	3,530
Greasewood	3,680	3,680	160
***Sulphates* (Glauber's salt).**			
Dwarf Samphires	314,040	314,040	314,040
Bushy Samphire	277,640	277,640	50,080
Cressa	275,520	275,520	134,880
Alkali-heath	275,520 34,530	323,200	1,560
Saltworts	44,160	104,040	1,560
Greasewood	36,160	36,160	960
Tussock Grass	19,640	323,200	19,640

*** This plant grows with equal luxuriance in soils containing only 680 pounds of carbonates.**

APPENDICES.

APPENDIX A.

DIRECTIONS FOR TAKING SOIL SAMPLES. ISSUED BY THE CALIFORNIA EXPERIMENT STATION.

In taking soil specimens for examination by the Agricultural Experiment Station, the following directions should be carefully observed; always bearing in mind that the examination, and especially the analysis, of a soil is a long and tedious operation, which cannot be indefinitely repeated.

First.—Do not take samples at random from any points on the land, but consider what are the two or three chief varieties of soil which, ***with their intermixtures***, make up the cultivable area, and carefully sample these, each separately; then, if necessary, sample your particular soil, noting its relation to these typical ones.

Second.—As a rule, and whenever possible, take specimens from spots that have not been cultivated, nor are otherwise likely to have been changed from their original condition of "virgin soils"—*e.g.*, not from ground frequently trodden over, such as roadsides, cattle-paths, or small pastures, squirrel holes, stumps, or even the foot of trees, or spots that have been washed by rains or streams, so as to have experienced a notable change, and not be a fair representative of their kind.

Third.—Observe and record carefully the normal vegetation, trees, herbs, grass, etc., of the average virgin land; avoid spots showing unusual growth, whether in kind or in quality, as such are likely to have received some animal manure, or other outside addition.

Fourth.—Always take specimens from more than one spot judged to be a fair representative of the soil intended to be examined, as an additional guarantee of a fair average, and mix thoroughly the earth *taken from the same depths.*

Fifth.—After selecting a proper spot, pull up the plants growing on it, and sweep off the surface with a broom or brush to remove half-decayed vegetable matter not forming part of the soil as yet. Dig or bore a vertical hole, like a posthole, and note at what depth a change of tint occurs. In the humid region, or in humid lowlands of the arid, this will usually happen at from six to nine inches from the surface, and a sample taken *to* that depth will constitute the "soil."

In California and the arid region generally, very commonly no change of tint occurs within the first foot, sometimes not for several feet; hence, especially in sandy lands, the "soil" sample will usually be taken to that depth, so as to represent the *average of the first foot* from the surface down.

Samples taken merely from the surface, or from the bottom of a hole, have no definite meaning, and will not be examined or reported upon.

Place the "soil" sample upon a cloth (jute bagging should not be used for the purpose, as its fibres, dust, etc., become intermixed with the soil) or paper, break it up, mix thoroughly, and put *at least a quart* of it in a sack or package properly labeled, for examination.

This specimen will, ordinarily, constitute the "soil." Should the change of color occur at a less depth than six inches, the fact should be noted, but the specimen taken to that depth nevertheless, since it is the least to which rational culture can be supposed to reach.

In the same way take a sample of each foot separately to a depth of at least three feet; preferably four or five, especially in the case of alkali soils, or suspected hardpan.

Sixth.—Whatever lies beneath the line of change, or below the minimum depth of six inches, will constitute the "subsoil." But should the change of color occur at a greater depth than twelve inches, the "soil" specimen should nevertheless be taken to the depth of twelve inches only, which is the limit of ordinary tillage; then another specimen from that depth down to the line of change, and then the "subsoil" specimens beneath that line.

The depth down to which the last should be taken will depend on circumstances. It is always necessary to know what constitutes the foundation of a soil, down to the depth of three feet *at least*, since the question of drainage, resistance to drought, root-penetration, etc., will depend essentially upon the nature of the substratum. In the arid region, where roots frequently penetrate to depths of ten or twelve feet or even more, it is frequently necessary to at least *probe* the land to that depth or deeper. The specimens should be taken in other respects precisely like that of the surface soil, *each to represent the average of not more than twelve inches.* Those of the materials lying below the third foot from the surface may sometimes be taken at some ditch or other easily accessible point, and if possible should not be broken up like the other specimens.

If there is *hardpan or heavy clay* present, an unbroken lump of it should be sent, for much depends on its character.

Seventh.—When in the case of cultivated lands, it is desired to ascertain the cause of differences in the behavior or success of a crop on different portions of the same field or soil area, do not send only the soil which bears unsatisfactory growth, but also the one bearing normal, good growth, for comparison. In all such cases, try to ascertain by your own observations whether or not the fault is simply in the subsoil or substrata; in which case a sample of surface soil sent for examination would be of little use. In such examinations the soil probe will be of great service, and save much digging or boring.

Eighth.—Specimens of alkali or salty soils should preferably be taken towards the end of the dry season, when the surface layers will contain the largest amount of salts. A special sample of the first six inches should in that case be taken separately by means of a post-hole auger, and then, in a different spot close by, a hole four feet deep should be bored, and *the earth from the entire four-foot column* intimately mixed before the usual quart sample is taken. Samples of the plants growing on the land should in all cases be included in the package, as they indicate very closely the agricultural character of the land.

All samples taken while the land is wet should be air-dried before sending; in the case of alkali soils this is absolutely essential.

Ninth.—All peculiarities of the soil and subsoil, their behavior under tillage and cultivation in various crops, in wet and dry seasons, their location, position, "lay," every circumstance, in fact, that can throw any light on their agricultural qualities or peculiarities, should be carefully noted, and *the notes sent by mail. Without such notes, specimens cannot ordinarily be considered as justifying the amount of labor involved in their examination.* Any fault found with the behavior of the land in cultivation or crop-bearing should be specially mentioned and described. The conditions governing crop-production are so complex that even with the fullest information and the most careful work, cases are found in which as yet the best experts will be at fault.

APPENDIX B.

SUMMARY DIRECTIONS FOR SOIL—EXAMINATION IN THE FIELD OR ON THE FARM.

While the general principles upon which the cultural value and adaptations of lands should be judged, have been given in the text of this volume, it seems advisable to summarize their practical application to land examination here, for convenient reference.

The directions given in Appendix I for the sampling of soils having been carried out, the samples so taken may be subjected to farther examination by any intelligent farmer to good purpose, and often with great saving of time and expense.

Spread the samples from the several depths in regular order upon a table or bench, and note the differences in color and texture apparent to the eye or touch, and whether they will or will not crush readily between the fingers, wet and dry. Whatever the fingers can do, can similarly be done by the harrow, cultivator, clod crusher or roller.

The tilling qualities of the surface soil and immediate subsoil are the first and most important matter to be ascertained; including especially their behavior to water. Place some airdried lumps in a shallow dish with a little water; observe whether they take up the water quickly or slowly, and whether in so doing the lumps fall to pieces or retain their form. Slow penetration, and maintenance of form, will at once indicate a soil somewhat refractory and difficult to till; while if the water is taken up easily and the lump falls to pieces, the land is easily cultivated and will absorb the rainfall and irrigation water readily. The darkening of the tint on wetting will also give an approximate idea of its humus-content.

Then take a wetted lump and work it between the fingers and on the palm of the hand, until its "stickiness" or adhesiveness ceases to increase. This "hand test" is of first importance and in skilful hands will largely supersede the need of elaborate mechanical analysis. It will at once enable the operator to classify the soil as a light or heavy loam, clay loam or clay soil; it will show directly what will be the result of plowing the land when wet, the liability to the formation of a plowsole, and whether a single or a double team will generally be needed to cultivate it properly. Also whether stock can be allowed to pasture the land soon after rain. Comparison with the known land of neighbors will also thus become easy, and in a measure the crops best adapted to the physical qualities of the soil, subsoil and substrata, taking into account their respective depths, will at once be at least approximately determined. The presence of coarse and fine sand in greater or less amounts will also be thus readily ascertained, allowing estimates of the percolative properties; the latter can, of course, be more practically tested in the field, in the manner described in chapter 13, page 242.

A more definite estimate of the amount and kind of sand present in the soil materials can be obtained by washing the *kneaded* sample into a tumbler, and allowing a thin stream of water to flow into it from a faucet while gently stirring the turbid water. The clay, together with the finest silts, will thus be carried off over the rim of the glass, and sand of any desired degree of fineness, according to the strength of the stream of water used, will be left behind. The kind and amount of these sandy materials can then be estimated, or definitely ascertained by weighing or measuring.

This will, generally speaking, be as far as the uninstructed farmer can readily go; but these simple operations will give him an insight into the nature of his soil and subsoil that will enable him to avoid a great many costly mistakes.

RECOGNITION AND MEANING OF THE SEVERAL SOIL MINERALS.[1]

Those somewhat familiar with scientific methods and operations, and supplied with pocket lens or microscope, can profitably go much farther towards the definite ascertainment of the permanent cultural value of the land, by the study of the minerals of which the sand is composed, and which as a rule represent those from which the entire soil has been formed; therefore indicate in a general manner its chemical composition. Such examinations are specially feasible and important when soils are not far removed from their parent rocks, as in most of the arid region, and in the states north of the Ohio. In the Southwestern states, in the coastal plain of the Gulf of Mexico, the original soil minerals have usually been too far decomposed to admit of definite identification. Sand is there as a rule made up of quartz grains of many varieties, with only an occasional tourmaline and pyroxene.

Among the prominent soil minerals, quartz is almost always recogniz-

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[1] For more details see chapters 3 and 4.

able by its glassy lusterand the irregular fracture—absence of definite planes or facets of cleavage, causing the grains to be abraded or rounded nearly alike in all directions. The *feldspars*, on the contrary, always show a tendency to cleave into fragments having definite, obviously oblique angles, which are perceptible even when the grains are somewhat worn; because of the difference in the ease with which wear takes place in the several directions. *Potash feldspar*, moreover, which is the most important to be recognized because it indicates a relatively large supply of potash in the natural soil, is but rarely glassy in luster, but mostly dull white, or reddish-white.—The *lime* and *lime-soda* feldspars rarely show as definite forms, because of their tendency to form complex crystalline aggregates (twins): and their definite recognition requires somewhat complex (polarizing) appliances in connection with the microscope. In such cases, however, the accompanying minerals (hornblende, pyroxene, mica and others) often afford valuable indications, because of their known association with soda-lime feldspars in certain rocks.

An abundant occurrence of *hornblende* fragments, characterized by their flat, tabular form, and bottle-green or black tint, indicate, almost always a fairly good supply of lime in the soil, but leaves the potash-supply in doubt. *Pyroxene* (distinguished by its smooth, polished surface from the angularly-weathering, usually rusty hornblende fragments) rarely occurs with potash feldspar; and soils strongly charged with it are mostly poor in potash.

Mica occurs in so many rocks and is of so little consequence as a soil--ingredient from the chemical point of view, because of its difficult decomposition, that its presence can mostly only serve to corroborate or contradict conclusions as to the derivation of a soil from some particular rock or region. But mica serves a good purpose in improving the tilling qualities of soils. Its thin scales must not be mistaken for the tabular fragments of hornblende.

Calcite in its several forms is mostly easily recognized both by its form under the microscope, and by the effervescence its granules show when touched with an acid. This effervescence can generally be observed on touching the wetted soil with chlorhydric acid, so soon as the content exceeds two per cent; but something depends upon the size of the grains, as when these are very small, the giving-off of gas is less readily noted. To facilitate it, the wetted soil may be warmed before touching it with the acid. The recognition of the presence of lime carbonate in soils is so important as to justify considerable trouble in rendering it definite. When the aid of a chemist cannot be commanded, fairly definite conclusions may be drawn from the character of the native vegetation; regarding which, detailed information may be found in Parts III and IV of this volume. But where, as in the arid region, this criterion is not available, since the controlling factor there is the moisture supply, a presumption may be gained by the application of a slip of moistened red litmus paper to the *wetted* soil. Should the red paper be turned blue within one or two minutes it would indicate the presence of carbonate of soda ("black alkali") as well as of lime carbonates: but if blued only after twenty minutes or more, it would indicate the presence of the carbonates of lime and magnesia. If not changed at all, the conclusion would be that either lime carbonate is in very small supply, or that the soil is in an acid condition. (See chapter 8, p. 122).

Saline and Alkali Soils.—The presence of an unusual or injurious amount of *soluble salts*, as in the case of seacoast and alkali soils, is commonly easily ascertained in the field; where, if the surface soil is at all seriously contaminated with soluble salts of any kind, these may be seen on the surface during a dry season, forming a whitish efflorescence, which in most cases is definitely crystalline. In doubtful cases a tablespoonful of the surface soil may be leached with water, and the first ten or fifteen drops caught in a clean, bright silver spoon and evaporated. Or the soil may be stirred up with about twice its bulk of water and the mixture be allowed to clear by settling, then evaporating. A slight whitish film will almost always remain in the spoon; but if the amount be somewhat considerable, the presence of soluble salts is very readily recognized by pouring a few drops of clear water on one side of the spot, and then allowing it to flow gently over the spot to another place, where it is again slowly evaporated. Any considerable amount of salts present will be shown both in the diminution of the original spot, and in the soluble residue accumulated where the water was last evaporated. Should *common salt* be present to any considerable extent, the residue in the silver spoon will, if the last drops be allowed to evaporate slowly, show square or cubical crystals to the naked eye, and certainly to a common pocket lens. The residue may also be tested with red litmus paper for carbonate of soda, which would quickly turn it blue.

More detailed examination requires chemical reagents and experience, but the above tests should be sufficient to prevent the mistaking of mere white spots, whose humus has been destroyed by fermentation caused by bad drainage, with true alkali caused by excess of soluble salts; a mistake not uncommon in both the arid and humid regions.

APPENDIX C.

SHORT APPROXIMATE METHODS OF SOIL EXAMINATION USED AT THE CALIFORNIA EXPERIMENT STATION.

BY R. H. LOUGHRIDGE.

THE California Experiment Station has for many years given the farmers of the State the privilege of having their soils examined to ascertain any physical defects, deficiency in plant-food, or the presence of alkali salts. They have quite generally taken advantage of this, and the number of samples of soil sent in each year has been very large.

A complete analysis of a soil-sample requires fully 15 days; hence the necessity of adopting some quick methods for the determination of the main elements of fertility, viz., humus, lime, potash, and phosphoric acid, that would at the same time give results sufficiently accurate for practical purposes. Similarly for alkali salts in the soil; the leaching-out and analysis of which often occupies more than a week.

The following methods have been adopted, which shorten the time of examination for the plant-food of a soil to about one hour, except for potash, which requires a much longer time. For alkali salts the time is reduced to two days, and less if a pressure filter be used.

Humus.—The Grandeau method of ammonia extraction requires the removal of the lime and magnesia with weak hydrochloric acid, washing out of the acid and then digestion with weak ammonia; all of which, with a soil rich in humus, may require many days, though a number of samples may be put through at the same time.

The method adopted to determine adequacy or inadequacy of the humus (for this is all that is intended in this examination) is completed in less than half an hour. It is based on the color of the humus-extract and avoids the necessity of removal of the lime from the soil.

The soil is pulverized in a mortar with a rubber pestle, and passed through a half-millimeter sieve. Seven grams of the fine earth is placed in a test tube with 15 or 20 cc. of a ten per cent solution of caustic potash and boiled for ten or fifteen seconds, then allowed to settle. The humus is dissolved and the density of the color of the solution is an indication of adequacy or inadequacy. A dense black, non-translucent solution shows the presence of at least one per cent of humus in the soil; a deep brown translucent color indicates about one-half of one percent; while a light brown color clearly shows a deficiency in the soil, and a need of a good green-manure crop.

Lime.—Two grams of fine earth is treated with a little hydrochloric acid, boiled for a few seconds, and ammonia is added to precipitate the iron and alumina; the whole, with the soil-residue, is quickly thrown on a filter to separate the mass from the lime solution, and washed. After adding ammonium chlorid the lime is precipitated with oxalate of ammonia, and its adequacy for soil-fertility judged of by the turbidity of the solution, or the bulk of the precipitate. Or the latter may be filtered off, dried and weighed. We thus obtain a measure of the carbonate and humate of lime present, by comparing it with the precipitate obtained from a soil whose percentage of lime has been correctly ascertained.

Potash.—The determination of potash in the soils requires more time than either of the other ingredients, and is more rarely made by us. Our knowledge of the soils of the State of California obtained through mvny analyses, gives us a clue to those localities where potash would probably be deficient, as well as to those whose soils are generally extremely rich in potash; the percentages reaching usually from .5 to as much as 1.5 per cent and more.

For the determination, two grams of the fine earth is digested in hydrochloric acid over a steam bath for two days, the insoluble residue filtered off, the filtrate evaporated to dryness to render the silica insoluble, again filtered and the iron, alumina and lime removed by precipitation with ammonia and oxalate of ammonia and filtration. The filtrate is then evaporated to dryness, the ammonia salts destroyed with *aqua regia* or driven off by heat, and the alkalies changed to chlorids. Any residue is then filtered off and platin-chlorid added to precipitate the potash, which is separated and determined in the usual way, either by reduction of the platinum by ignition, or by measurement in a Plattner's potash tube.

Phosphoric Acid.—The determination of phosphoric acid is based on the volume of the phospho-molybdate precipitate in a tube made like a Plattner's potash tube, but having a wider interior diameter for the smaller portion (not greater than 3 millimeters), and a length of 50 mm. With this diameter, one mm. in height of the precipitate obtained by our short method indicates one one-hundredth of one per cent of phosphoric acid in the soil. The unit of measure must be obtained for each tube, unless of uniform diameter, and is ascertained by taking a soil whose phosphoric-acid percentage has been determined gravimetrically and giving it the following quick treatment; which must, of course, be closely followed in each soil to be examined:

Two grams of the fine earth is ignited in a platinum dish to destroy the organic matter, transferred to a test-tube containing 5 cc. of nitric acid and made to boil for only a couple of seconds, thus preventing the solution of silicates to any material extent. It is not allowed to stand, but a little water is immediately added and it is quickly thrown on a small filter and washed with a little water. The phosphoric acid is then precipitated with molybdic acid at the proper temperature; allowing it to settle, the liquid is drawn off and the precipitate transferred to the measuring-tube. It settles into the small part in a short time if the latter is not too narrow, and is then measured with a millimeter scale. This represents the percentage as found in the soil by the gravimetric method, and serves as a guide for other examinations, whose agreement with gravimetric determinations is generally quite close, and quite sufficient for practical purposes. The rapidity with which the solution is made and separated from the soil is a matter of special importance for comparative results, or determination of percentages; for if the acid solution be allowed to stand for some time before filtration from the soil, silica passes into solution also, and the volume of the molybdate precipitate is increased by it; thus vitiating the results and adding to the time required for the method. By this short method the practically important phosphoric acid in the soil may be approximately determined within half an hour.

SHORT METHOD FOR ALKALI SALTS.

The old method of obtaining solutions of the salts by leaching the soil on a filter until all of the alkali had been washed out has been replaced by the following short one. 50 or 100 grams of the well-mixed soil is placed in a bottle containing 200 cc. of water, shaken up occasionally during 12 hours and allowed to settle. The solution may then be passed through a common filter (or preferably a pressure filter) and an aliquot part (usually 50 cc.) of the filtrate evaporated to dryness in a platinum basin and ignited at a temperature just below redness to destroy any organic matter that may be present. The basin and contents are weighed and the soluble salts are dissolved in a very little water and separated by filtration through a small filter into a 50 cc. cylinder and the alkali carbonates and chlorids determined by titration, being calculated as sodium compounds.

The material remaining on the filter and in the basin, consisting of insoluble earth, carbonates and calcium sulfate, is gently ignited in the basin and weighed; the difference between this and the first weight gives approximately the *total soluble salts*, which should substantially correspond to the titrations made.

The sulfates are determined by differences between these and the total alkalies. The solution may contain some sulfate of magnesia, or calcium and magnesium chlorids, and these are determined gravimetrically.

Nitrates, which may have been destroyed in the first ignition, are determined in the original solution by the picric method. Any magnesia rendered insoluble by the ignition may usually be accounted for as chlorid, unless much nitrate is present which is rarely the case in carbonated alkali. If much nitric acid was found, it should be first assigned to magnesia.

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AUTHORS REFERRED TO.

[NOTE.—In cases where no special credit is given in this volume for investigations made or data given from the Southwestern States and the Pacific Coast, these should be understood as work done, mostly under the writers direction, or by himself and assistants, in connections with the geological surveys of Mississippi and Louisiana, as well as the Tenth Census of the United States, by Drs. Eugene A. Smith and R. H. Loughridge; the chemical work for the Pacific Northwest, under the auspices of the Northern Transcontinental Survey, by M. E. Jaffa and Geo. E. Colby; that in California, at the Experiment Station, by the latter two, Dr. R. H. Loughridge, and temporary assistants. It would be impossible to segregate, without excessive prolixity, the credit to be assigned to each of these participants.]

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* This writer's valuable "Boden Runde" (1905) unfortunately came to hand too late to be considered in this volume.

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